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Description

The present invention relates to an opto-electronic angle measurement device, methods for calibration of said device for two-dimensional (spatial) angle measurements, and use of said device in position and geometry measurement systems, as well as an opto-electronic system for simultaneous measurements of the three dimensional coordinates of a plurality of points on a surface.

More specifically the invention relates to an opto-electronic sensor for measuring directions in two dimensions to point sized active light sources or to points illuminated by light sources. Said opto-electronic angle measurement device is calibrated once and for all for angle measurements in two dimensions (spatial direction) towards light sources or light reflecting points illuminated by one or more light sources, using a high precision angle reference.

Furthermore, the invention relates to a general opto-electronic system for spatial coordinate measurements for one or more light sources or light reflecting points illuminated by one or more light sources, including at least two angle sensors. Said system is applied for non-contact measurements of object position, orientation, and/or surface geometry.

The invention includes a method to determine the location of the rotational axes of the lens-system of said opto-electronic sensor, as well as methods for calibrating said opto-electronic sensor for measuring the angular direction in two dimensions to a light source or to a point illuminated by a light source.

Furthermore, the invention relates to an opto-electronic system for simultaneous measurement of the coordinates of a plurality of points on a surface, comprising a device designed to project a plurality of light spots on a surface in combination with angle sensors. This device consists of one or two gratings, dividing a collimated light beam into multiple beams which are focused to a pattern of point sized light spots on the surface, e.g. as described in Applied Optics, Vol. 23, No. 2, January 15., 1984, pages 330 - 332.

Non-contact angle measurements are conventionally done by using a theodolite which is aimed manually at the target. The state of the art in this field is fully automatic, servo controlled theodolites as manufactured by Kern and Wild Leitz. Such devices can be automatically aimed at targets of known shape if the approximate positions of the targets are known. Thereby angles in two dimensions can be read automatically. The fact that the theodolite is physically directed towards each target using a servomotor system, means that the system has a very limited measurement frequency.

Non-contact, automatic geometry measurements are in great demand for surface profile surveying, e.g. in automotive industry. Today, mechanical coordinate measurement machines (CMM's) are used for these applications. CMM's are expensive, complex, inflexible and most of them are in direct contact with the surface. These limitations make them unapplicable in production line setups, hence, present quality control is based on spot testing by templates.

Present opto-electronic systems can be divided in three categories according to their measurement principle: structured light, range measurements (optical radar) and triangulation techniques.

Structured light techniques are based on projection of light spots or lines onto a surface to measure its shape, e.g. Moiré-techniques. Common characteristics of these techniques are that the image of the projected pattern is registered using video cameras or conventional photography, and that a reference surface or an image of a reference pattern is needed to calibrate the system in its actual setup.

Range measuring techniques, usually based on measuring the time of flight of a laser pulse, have a very high depth resolution, but low lateral resolution and a limited measurement field.

Several companies manufacture opto-electronic systems based on triangulation, e.g. Seatex in Norway or Sagem in France. Their systems use a single opto-electronic sensor, and include the direction of the laser beam as the second known direction for their triangulation calculation. The difficulties of accurately and stable directing a laser beam restricts the accuracy of the systems, and on-site calibration is necessary. The need for a fixed, well known baseline limits the flexibility of the work range.

US-A-4,710,028 discloses a low accuracy angle measurement system for measuring angles between a reference direction and the direction of an object, such as a missile.

It is an object of the present invention to obtain a system for static or dynamic high precision measurement of the position, orientation and/or surface geometry of any object, overcoming the drawbacks of present measurement techniques.

Furthermore, it is an object of the present invention to produce a fully automatic and non-contact angle sensor which is factory-calibrated once and for all for high precision measurements. No further calibration is necessary in a measurement setup, except for definition of coordinate systems. Furthermore, the object of the present invention is that the angle sensor shall not contain any moveable parts, shall be nearly insensitive to background light, and allow for simultaneous measurement of angles for several points.

Finally the present invention enables very fast and accurate measurements of the three dimensional coordinates of a plurality of points on a surface.

The present invention is defined in the appended claims.

According to an apparatus aspect of the present invention, the characteristic features of the sensor are :-

image processing means operable to compute the spatial direction of said light sources or illuminated reflecting points from the uncorrected position of an image of said light sources or illuminated reflecting points as registered in the local coordinates system of said array of photosensitive elements,

said image processing means including a two-dimensional calibration table relating said uncorrected position in said local coordinate system to the angles defining spatial directions, the calibration table being generated by a single calibration provided by means operable to determine the center of rotational symmetry of the angle sensor lens and determine the geometrical errors of the sensor means to provide the relationship between the spatial directions and a position of the image on the photosensitive array, and

said image processing means having means for effecting statistical analysis of the intensity distribution by correcting and comparing said intensity values registered by multiple neighbouring photosensitive elements for increasing the resolution and accuracy of the angle measurement which are otherwise limited by the size of said photosensitive elements.

According to a method aspect of the present invention, the characteristic steps are :-

effecting a single calibration enabling said angle sensor to be used at various locations without requiring any recalibration, the calibration step comprising :

determining the centre of rotational symmetry of the angle sensor lens, by correction of the position of an adjustable mounting fixture attached to the angle sensor in a position corresponding to the rotational axes of said sensor, such that if the lens optical axis is defined as the x axis, the z axis of the angle sensor is defined by the vertical symmetry axis of said mounting fixture and the y axis is defined by its orthogonality to said x and z axes, by defining rotations around the z axis as horizontal angles and rotations around the y axis as vertical angles, by mounting the angle sensor onto a rotary table and levelling to ensure that the optical axis is horizontal, by mounting a minimum of two light sources at approximately the same level as the optical axis, such that a straight line can be drawn through the two light sources and the rotational axis of the rotary table, and by adjusting the mount of the angle sensor to the rotary table until the images of the two light sources are over-lapping, whatever the rotary position of the angle sensor, and clamping said mounting fixture to the angle sensor in this position,

calibrating said angle sensor for measurement of angles relative to said two rotational axes, by using a substantially vertically mounted linear device comprising light source means in the form of either an array of light sources or illuminated reflecting points or an illuminated string or slit, said linear device having a length corresponding to the field of view of the angle sensor in one dimension, by levelling the angle sensor such that one of its rotational axes is exactly vertical, by having said linear device mounted parallel to said rotational axis, and

either having said angle sensor mounted on a high position rotary table so that one of said rotational axes is also parallel and coincides with the rotational axis of the rotary table, and step-wise rotating the angle sensor while the image of the linear device and the corresponding rotary table angle are simultaneously registered for every step,

or by step-wise moving said linear device in a known direction crossing the sensor optical axis, and registering the horizontal position of said linear array of light sources or reflecting points and its corresponding image simultaneously,

thereby to determine the relation between the angle and the position of the image on the photo sensitive array; and

repeating this procedure for the second rotational axis of the angle sensor, followed by processing of all data to establish a two-dimensional calibration table relating image coordinates to spatial direction given as horizontal and vertical angles,

said calibration being based on using light source means having well defined and known spectral distribution, and

statistically analysing values of intensity registered by multiple neighbouring photosensitive elements to increase the resolution and accuracy of the angle measurements which are otherwise limited by the size of said photosensitive elements.

The photosensitive elements can e.g. be CCD- or CID-sensors. The well-defined centre of rotational symmetry of the lens gives an unambiguous definition of spatial directions, by all points having the same direction relative to this point is imaged in the same point on the sensor.

The use of the angle sensor is restricted to measurement of the direction to active light sources or light reflecting points illuminated by active light sources having the same spectral distribution as those that were used for calibration. This ensures high measurement accuracy as a high signal-

to-noise ratio is obtained and no chromatic aberration contributes to the error.

Two practical implementation are proposed for said linear array of light sources used to calibrate the opto-electronic angle sensor. Automated calibration procedures are suggested, allowing for a high number of registrations, and hence ensures high precision.

In accordance with another aspect of the present invention, the characteristic features of the above mentioned general geometry measurement system are:

that said system includes dedicated image processing units for processing the image registered by each angle sensor to two dimensional angular values for each light source or illuminated point,

that said system includes a data processor for computation of the coordinates of each light source or illuminated point in a 3-dimensional spatial coordinate system having three axes, and

that said data processor includes means to obtain the relationship between the internal coordinate systems of the individual angle sensors and the spatial coordinate system, the data processor carrying out one of the following operations:

following the mounting of the angle sensors so that they are aligned parallel to one of said axes and are in known positions, calculating their orientations from the measured spatial directions to a light source or an illuminated point which is located in a known position and thereby used as a common reference point,

by designing said data processor for calculation of the positions and orientations of the angle sensors on the basis of measured directions to at least three light point sources in known spatial coordinates,

by designing said data processor for calculation of the positions and orientations of the angle of the angle sensors on the basis of measured directions to a number of given light points, where the mutual separation distance is known for at least two thereof, and the position of a third point relative to said two define the orientation of the spatial coordinate system.

Further characteristic features of the angle sensor and the general geometry measurement system, as well as applications of said system, are given below.

The characteristic features of the opto-electronic system for measuring spatial coordinates of a plurality of points located on a surface are:

that the system includes means to illuminate the surface point by point, comprising a directed light source emitting a light beam, a diffraction grating made up from multiple optical fibres or a technically equivalent diffraction grating, and focusing optics to obtain a pattern of well defined discrete point sized light spots forming a curved line across the surface,

that the system includes a minimum of two angle sensors to register the location of the projected light spots as spatial directions relative to said angle sensors, and

that means are included to compute spatial coordinates for each discrete light spot based on the registered spatial directions relative to the angle sensors.

Further characteristic features of the present invention are given in the following description of examples being non-limitative to the invention, with reference to the accompanying drawings.

Fig. 1 a-b	illustrate the basic components of an angle sensor.
Fig. 1 c	shows the angle sensor from below.
Fig. 2 a-c	illustrate the angle measurement principle.
Fig. 3 a-b	illustrate a method for adjustment of the angle sensor mount relative to the centre of rotational symmetry.
Fig. 4 a-c	illustrate a method for angle sensor calibration, using an illuminated string or slit.
Fig. 4 d	illustrates the angle sensor mount for horizontal and vertical angle calibrations.
Fig. 5 a-b	shows a mechanical device used to tilt and rotate the angle sensor.
Fig. 5 c	illustrates a mechanical device used to tilt and rotate the angle sensor for vertical angle calibration.
Fig. 6 a-e	illustrate a method for angle sensor calibration, using an array of active light sources or illuminated spots.
Fig. 7	is a block schematic view of a general geometry measurement system.
Fig. 8 a-d	illustrate various applications of the geometry measurement system.
Fig. 9 - 10	illustrate dividing a laser beam into a plurality of beams to form a plurality of focused spots along a straight line.
Fig. 11	illustrates the use of two mutually orthogonal gratings to form a two dimensional pattern of focused spots.
Fig. 12	illustrates a system configuration for surveying a surface profile, including two angle sensors, a laser and two gratings used to form a

two dimensional pattern of focused spots.

Fig. 13 illustrates the use of one grating and a rotary mirror to scan a surface.

The present invention for position and geometry measurements is based upon a fully automatic and accurately factory-calibrated angle sensor as illustrated in figure 1. The angle sensor is built up as a conventional solid state video camera, consisting of a camera housing 1, a lens 2, and a two-dimensional array 3 of photosensitive elements 11. The lens is a standard spherical camera lens, having a focal length mainly given by the field of view requirements. If the lens possibly has an anti-reflection coating or optical filter, it has to be matched to the spectral distribution of the light sources to be used. The photosensitive elements may for example be CCD's (Charge Coupled Device) or CID's (Charge Injected Device). Due to the high precision specifications, arrays of highest available resolution are used. In systems where the measurement speed is the number one priority, lower resolution arrays are used.

Camera of said type is commercially available. This camera is made into an angle sensor by the fact that the lens 2 has a well defined and known centre of rotational symmetry 7, defined by the fact that the images of points located in the same direction relative to this centre are exactly overlapping. This centre of symmetry is always located on the optical axis. A spatial direction is given as angles relative to two orthogonal axes. In this case any pair of mutually orthogonal axes having origin in said centre of symmetry, and being normal to the optical axis, could be used. According to conventions, a horizontal and a vertical axis are used. The two axes are parallel to the horizontal and vertical axes of the camera housing. A mechanical mounting fixture 4 can be adjusted by the use of slits 8 and bolts 9 to define the vertical axis of rotation 6. Due to the spherical optics, the corresponding horizontal rotational axis is defined by its orthogonality to the vertical axis and the optical axis. The angle sensor is calibrated to measure angles in two dimensions relative to these two rotational axes.

Figure 2 a illustrates the principle of measuring the spatial direction. The fully automatic function of the angle sensor is based on the use of active light sources, e.g. light emitting diodes, or points 10 illuminated by active light sources, e.g. lasers or laser diodes, directed towards a surface. The lens 2 images the light point source 10 onto the array 3 of photosensitive elements 11 as an illuminated spot 12. The image provides illumination of a number of the photosensitive elements 11 with an intensity distribution given by the size of the light point source 10, and the optical resolution of the lens 2. The position of the light spot 12 on the array, is a unique measure of the spatial direction to the imaged point 10. The spatial direction is given as two angles α and β. β is the angle between the spatial direction and the horizontal level of symmetry given by the angle sensor, α is the angle between the optical axis and the direction to the projection of the light point source 10 onto the horizontal level of symmetry. α and β are both 0 for points along the optical axis.

For most applications, the resolution of the photosensitive array by itself is too low. To improve the resolution, the position of the light spot on the array is calculated more accurately using a statistical analysis of the intensity distribution, e.g. a centre of gravity calculation as illustrated in figures 2 b and 2 c.

The lens 2 has an aperture angle limiting the measurement area of the angle sensor. A typical field of view is 30 degrees both horizontally and vertically. No strict requirements are set to the lens distortion properties, as these are corrected by the calibration method, hence a distortion free lens is not required. Due to this large field of view, any mechanical rotation of the angle sensor to aim it at the measurement point as with conventional or automatic theodolites, is avoided. The angle sensor is calibrated at a fixed focus distance. The lens depth of field restricts the longitudinal work range of the angle sensor.

The angle sensors are designed to measure the directions to light sources emitting light at a well defined spectral distribution, usually in the visible or near infrared spectral region. The position of the focal plane, and hence the image of a light spot depends on the spectral distribution of the light. Thus the angle sensor is calibrated to be used at well defined wavelengths, and the calibration is made using active light sources or points illuminated by light sources having this spectral distribution. This technique ensures high accuracy, and enables automatic separation of the light point sources in question from the background. The signal-to-noise ratio is improved using an optical filter matched to the spectral distribution of the light sources. The filter has to be mounted prior to calibration due to its optical influence on the lens system.

The proposed applications of the angle sensors rely on high precision angle measurements. Hence accurate methods are needed to determine the centre of rotational symmetry and to calibrate the angle sensors. To obtain a high calibration accuracy, a large number of calibration measurements has to be made. Hence, extensive work has been carried out to develop fully automatic calibration methods.

As mentioned in the introductory part, the present invention is based on the existence of a centre of rotational symmetry giving an unambiguous definition of the direction towards light spots. The definition of the centre of rotational symmetry of the lens is that all light sources or illuminated points located in the same direction relative to this point are imaged at exactly the same point at the focal plane of the lens. This means that the position of the intensity maxima registered by the photosensitive array are the same for all such points. This definition is used to adjust the position of the mounting fixture 4 as illustrated in figures 3a and 3b.

The angle sensor is mounted onto the top of a rotary table 13 and levelled. A minimum of two light sources 14, 15 are mounted in a line in the horizontal symmetry plane of the angle sensor. If the setup is observed from above as in figure 3b, an exactly straight line can be drawn through the rotational axis of the rotary table and the two light sources. The heights of the two light sources are allowed to differ slightly to form two different image spots on the photosensitive array. Larger height differences may cause errors due to lens distortions. The mutual separation of the two light sources is restricted by the lens depth of field.

The adjustable mounting fixture 4 is moved parallel to the optical axis of the lens until the horizontal positions of the intensity maxima of the two image spots coincide for any rotation angle θ of the angle sensor. To obtain maximum sensitivity, the angle sensor is rotated to the very limits of its field of view. The mounting fixture is clamped in the correct position using the bolts 9.

This method determines the vertical rotational axis 6 (z-axis) of the lens, and hence an unambiguous definition of the centre of rotational symmetry is where the z-axis 6 intersects the optical axis 5. Thus the mounting fixture determines the vertical rotational axis, which defines horizontal angles.

The third axis of symmetry (y-axis) is defined by its orthogonality to the optical axis and the vertical axis as found above, and their common origin. The standard angle sensor does not have any mounting fixture related to this axis. A mounting bracket 19 is used to determine this axis for the calibration procedure, as described below. This bracket is dismounted after calibration.

The principle of the angle sensor calibration methods is to mount the angle sensor onto the top of a rotary table, and to register the image positions of a linear array of light sources or illuminated points as a function of rotational angle as the rotary table is rotated step by step. The angle sensor should be calibrated under conditions resembling those of a real measurement setup. Two alternative calibration methods have been developed. A technique that uses point-sized active light sources is described below. A simpler calibration method is based on replacing the separate light sources with a linear light source, e.g. an illuminated string or slit.

Calibration by the use of a linear light source is illustrated in figure 4a. The angle sensor is mounted onto the top of the rotary table 13. The rotary table includes a high precision angle reference, and is servo controlled to allow for automatic function. The angle sensor is levelled, and the position of the mounting fixture is adjusted as described above. Thus the rotational axes of the angle sensor and the rotary table coincide. A linear device is mounted vertically. In the following description a string 16 is used as an example of a such a linear device. However, e.g. a slit can be used in a similar manner, except for the illumination technique. In the case of a string, it is illuminated to give diffusely reflected light to be registered by the angle sensor. If a slit is to be used, it would be mounted in front of an illuminated background to form a narrow illuminated line.

The easiest way to mount an exactly vertical string is by attaching a plumb bob 17 to it. The length of the string corresponds to the vertical field of view of the angle sensor. The string is illuminated by a light source 18. This illumination covers all or parts of the string. Point by point illumination can be used to obtain closer resemblance to the point sized light sources used in an actual measurement setup. In such a case, the light spot can be moved up and down the string by the use of a rotary mirror.

The image of the string has a line-shaped intensity distribution, as shown in figure 4b. The line has a curvature given by lens distortions as illustrated in figure 4c. As the table is rotated stepwise, the position of the image of the line as registered by the photosensitive array, is measured as a function of rotary angle. As an alternative way, a similar result can be obtained using a fixed angle sensor, by moving the string linearly and horizontally in a well defined way relative to the optical axis of the lens.

The calibration procedure is repeated after rotating the angle sensor 90 degrees around its optical axis, and mounting it to the top of the rotary table using the bracket 19 as shown in figure 4d. The two sets of data are processed to form a two-dimensional calibration table, to be stored in a two-dimensional memory array in the corresponding image processing unit.

The second calibration method is based on using a plurality of light sources mounted in a vertical, one-dimensional array. To achieve the required accuracy, a large number of light sources

has to cover the entire vertical field of view. According to the present invention, the accuracy can be improved without increasing the number of light sources, using a method based on stepwise tilting the angle sensor. For each tilted position, a part of the photosensitive array is calibrated. Using this method, the light sources can be reduced to a short one-dimensional array covering a part of the vertical field of view only.

Two dedicated mechanical tilting devices, as shown in figures 5a, 5b and 5c, and numbered 21 or 23, have been developed to tilt the angle sensor around a horizontal axis normal to the optical axis. The two alternative devices 21 or 23 are used depending on which of the two rotational axes that is to be calibrated. To calibrate the vertical axis, the device made up from the brackets 20 and 21 as mounted to the angle sensor and rotary table, respectively, is used. The two brackets 20, 21 are connected using a rotary adapter 22. To calibrate the horizontal axis, the bracket 23 is mounted to the angle sensor using a rotary adapter 24.

The angle sensor, including the tilting device, is mounted onto the rotary table 13 and is then levelled. The setup is illustrated in figure 6a. In this levelled position, the angle sensor is rotated around the vertical axis (z-axis), as shown in figure 6b. The calibration curves as illustrated in figure 6c, are obtained by simultaneous measurements of the angle of the rotary table 13, and the sensor position of the image of the individual light sources 25-27. In this position the middle part of the photosensitive array is calibrated. To calibrate the rest of the array, the angle sensor is tilted as illustrated in figure 6d. The tilt angle is measured, and the method is repeated, i.e. the rotary table is stepwise rotated, while the rotary angle and the image position is simultaneously registered to calculate the calibration curves, until the total field of view has been completely surveyed.

The tilt angle can be measured using an inclinometer. Alternatively the angle sensor itself can be used, by having this precalibrated in the two symmetry planes (corresponding to $\alpha = 0$ or $\beta = 0$ in figure 2a). Such a calibration is done by the use of one light source mounted in the same height as the centre of the angle sensor. To use this method for tilt angle measurements, a light source has to be mounted in this very same height.

The angle sensor is rotated 90 degrees around its optical axis, and the calibration method is repeated. In this position the mounting bracket 23 is used. Note that the angle sensor again is tilted around a horizontal axis.

Based on the registered data, a two-dimensional calibration table is calculated and stored in the corresponding image processing unit in a two-dimensional memory array.

As when using a linear light source as described above, the rotary table can be replaced by a fixed angle sensor mount if mounting the light sources to a device that can be moved linearly and horizontally in small steps in a well defined way relative to the optical axis of the lens.

All calibration curves can be verified, using the rotary table as a reference, and measuring the angles to light sources in well known positions.

Said angle sensors can be combined to a number of different turn-key measurement system solutions, dependent on utilization. A general block schematic view is illustrated in figure 7. The schematic view shows a system built up from two angle sensors 28a,b, allowing for measurements of spatial positions of a number of light sources. The image data are transferred from the angle sensors to dedicated image processing units 29a,b as a sequence of analog or digital intensity values for each of the individual photosensitive elements.

The following operations are executed in the image processing unit:

- exposure timing controls,
- digitization of intensity values,
- storage of digital image data in a two-dimensional memory array,
- subtraction of a background light-noise image given as a stored image, as measured when no light source is lit,
- peak detection to find estimated position of a number of intensity maxima,
- calculation of the exact image position of each individual light spot given in the coordinate system of the photosensitive sensor,
- conversion of the image position coordinates to angle values relative to the horizontal and vertical rotational axes, using a two-dimensional calibration table as stored in a separate memory array.

The system is designed to deal with a number of simultaneously active light sources, as long as their mutual positions are unambiguous.

The angle values are transferred to a central data processor 30 for further calculations. The standard version of the data processor contains means for computation of three dimensional coordinates using triangulation or photogrammetric methods. Further features depends on application and system configuration. Typical applications are explained below.

The design of the image and data processor units is based on commercially available image processing hardware and software components.

The data processor has a console 31 connected to it. This console consists of a monitor and a keyboard for operator control functions. For example, this unit is used for on-line and off-line display of measurement results.

In systems for measurement of surface geometry using a laser or laser diode to illuminate points on the surface, a driver unit 32 is connected to the data processor to control the laser 33 and a dual axes mirror 34. The mirror is used to direct the light beam 35 onto the surface, and to scan the surface 36 in two dimensions.

Using separate active light sources 38 - 40, e.g. light emitting diodes, these are connected to the data processor via a driver unit 37. The driver unit supplies the light sources with power, and contains timing circuitry to turn them on and off for exposure control according to timing information given by the data processor.

Figure 8a illustrates how the system is basically applied to measure the three dimensional coordinates of a light point source or illuminated point. A minimum of two angle sensors 28a,b measure the horizontal and vertical angles of a point 38 relative to a reference point 41. For this application the data processor includes conventional triangulation software, as commercially available. This software is based on known coordinates for the two angle sensors and the reference point, given in a global coordinate system.

Different approaches exist to measure the position and spatial orientation of the angle sensors relative to a global coordinate system. A primitive way is to measure their positions using conventional surveying techniques, and to find their orientation using a reference light source in a well known position To use this method, the angle sensors have to be levelled. A more sophisticated method is to measure the relative angles of three light sources in known global coordinates, and to calculate the angle sensor position and orientation from these measurements. A third method is bundle adjustments, which is based on measuring the relative angles of a number of light spots, the mutual distance being known for at least two of them and the coordinates of a third light source defining the orientation of the coordinate system. Bundle adjustments is an accurate method due to redundant measurements. The data processor includes software for the method to be used. This initiation routine must be run each time an angle sensor has been reoriented or moved to another position.

Using more than two angle sensors yields redundancy, and hence improve the reliability and precision of the measurements. By using only two angle sensors, redundancy is achieved for the z-coordinates.

To measure the six degrees of freedom position and orientation of an object 42 as shown in figure 8b, requires a minimum of three light sources 38 - 40 to be attached to the object. The positions of the light sources should be well known in an object oriented coordinate system. The global coordinates of the three light sources are measured using a minimum of two angle sensors 28a,b and a reference light source 41 as described above. The relation of the measured global coordinates to the corresponding local coordinates is used to calculate the position and orientation of the object oriented coordinate system relative to the global one.

Redundancy, and hence improved accuracy is obtained if the number of angle sensors or light sources is increased.

Figure 8c illustrates an application of the angle sensor for profile measurements. A minimum of two angle sensors 28a,b are used to measure the three dimensional coordinates of an illuminated spot 35. The spot is generated by a laser scanning system consisting of a laser 33, and a dual axes mirror 34 which is used to direct the laser beam towards the object 36. The laser beam is focused to achieve a minimum sized light spot. Similar to the use of a dual axes mirror as shown, the laser itself can be rotated using a dual axis rotary system.

The laser scan system, consisting of laser, dual axes mirror, dynamic focus module and drive electronics, is commercially available.

As mentioned above, the laser scan driver is controlled by the data processor. The mirror is rotated stepwise, the step increment being given by the measurement accuracy requirements. In the data processor there is software for intelligent surface scanning, e.g. to register whether the laser beam hits the surface or not, or to measure the change of the measured angles as a function of laser beam angle to adapt the step increments to the curvature of the surface.

The data processor contains software to calculate a mathematical model describing the geometry of the surface on the basis of the measured coordinate values. The data processor is designed to be interfaced to a user supplied CAD (Computer Aided Design) system, e.g. to compare the measurement results to nominal design parameters.

Using the method as described above, the three dimensional surface coordinates are given as global coordinate values. The global coordinates can be transformed to a local object oriented coordinate system. As an example, this is easily done if the object has a minimum of three reference points having well known local coordinates. Measuring the global coordinates of these points give the information necessary for a coordinate transformation.

The applicability of the laser scan technique is restricted by the fact that the system measures the coordinates of single points, one by one, and that the system contains mechanically moving parts. To

redirect the laser beam and to transfer all data from the photosensitive array are both time consuming processes.

For a number of industrial applications, the essential features to be measured are the deviations between a manufactured object and the design model in a limited number of critical check points. A system according to the present invention can be applied using a number of lasers or laser diodes 43 - 45 mounted in fixed directions, pointing towards the critical points 46 - 48, as shown in figure 8d. All illuminated spots can be processed in parallel, giving a very fast presentation of all essential dimensional deviations.

This method is expensive, due to the fact that a separate light source is needed for each point to be measured, and a small number of check points are achieved.

The disadvantages of both profile measurement techniques as described above are overcome by the use of a system for simultaneous measurement of the spatial coordinates of a plurality of illuminated points, generated by the use of a projection device that projects a pattern of focused light spots onto a surface. Such a device may be made up from a newly commercially available diffraction grating as described in Applied Optics, Vol. 23, No. 2, January 15., 1984, pages 330 - 332. These are based on parallel optical fibres, each fibre functioning as a cylindrical lens. The emitted light from the individual fibres interferes to form a close to ideal interference pattern. The characteristic features of these gratings are that the spot intensity is uniform, and that the spot diameter is close to that of the zero'th order beam. By mounting such a grating to the output of the laser, a large number of spots form a line across the surface.

A two dimensional pattern of illuminated points can be created in two ways. One is to use a single grating and to use a single axis rotary mirror to move the line of light spots across the surface. Another method is to mount two gratings together, to create a two dimensional pattern of light spots.

Technically equivalent means like conventional or holographic diffraction gratings can be used in similar ways. However, using the above mentioned type of angle sensors, conventional diffraction gratings are less applicable due to larger intensity and spot size variations.

A grating 49 consists of a large number of parallel optical fibres 50 arrayed as a monolayer as shown in figure 9. The figure illustrates a cross section of the grating. Each fibre 50 acts like a cylindrical lens. An incident plane wave 51 is split and focused by the fibres 50 into points 52 just behind the grating. From these points, cylindrical waves 53 are emitted, having wide angles of uniform intensity. Thus each fibre 50 can be considered as a light point source 52. The resulting diffraction pattern 54 corresponds to that of a conventional grating having infinitely small slit width. Such an ideal grating gives an infinite number of uniform intensity maximas. Using an optical fibre grating, typically 30 - 50 intensity maximas have an intensity higher than 50 % of the zero'th order beam.

A complete system designed to project multiple light spots onto a surface is shown in figure 10. It consists of laser 55, fibre grating 49 and focusing optics 56. The collimated laser beam 57 is diffracted by the grating 49, and focused onto the surface 36. The optical design depends on the specifications with respect to focus distance and spot size. The grating splits the laser beam to multiple beams projected as light spots 58 forming a curved line across the surface. The relative angle between the diffracted beams is constant, and is a function of the fibre diameter.

A two dimensional pattern of focused light spots is achieved by using an additional grating 59. This grating is mounted in such a way that the optical fibres (slits) are rotated relative to the first grating 49, as illustrated in figure 11. 90 degrees mutual rotation yields a rectangular pattern of light spots as shown in figure 12.

Figure 12 illustrates a complete system configuration for surface profile measurements. A two dimensional pattern of light spots 58 is projected onto a surface 36 by the use of two diffraction gratings 49, 59 and focusing optics 56. The three dimensional coordinates of each individual spot are found by measuring the spatial angles of each spot relative to two angle sensors 60a,b, e.g. sensors of the type described above. All light spots are simultaneously registered, such that for each image the photosensitive array contains a number of intensity maximas.

The system includes pre-processors 61a,b designed to register and process the data from the angle sensors. The design and function of the preprocessors depends on which type of angle sensors that are used as discussed below.

The angular data are transferred from the two pre-processors to a data processor 30 for three dimensional coordinate calculation. Standard triangulation or photogrammetric methods are used. This calculation is based on the existence of an unambiguous relationship between the data from the two angle sensors. This means that the system needs a way to identify which intensity maximum is corresponding to a specific light spot for every angle sensor, and thus the data processor includes a simple light spot recognition software. Another method is to manually identify each light spot prior to coordinate calculation.

Using one single grating, the identification procedure is simple. Across the photosensitive array a curved line of intensity maximas is registered. The curvature depends on the shape of the object.

Figure 13 illustrates the surveying of a surface using one grating 49 and a single axis rotary mirror 34 to generate a two dimensional light spot pattern (as shown in figure 12) by moving the line of illuminated spots 58 across the surface 36. The laser 55 and mirror 34 are controlled by a driver unit 32 connected to the data processor. The mirror is rotated stepwise, at a step length given by the pattern density requirements. A dense grid of light spots gives an accurate description of the surface geometry. The data processor may include software for intelligent scan control, e.g. to register if the laser beams actually hit the object, or to measure the sensor angle value changes to adapt the step length to the curvature of the object.

The angle sensors and the general geometry measurement systems described hereinbefore are very suitable together with this light projection technique. The geometry measurement system includes a minimum of two angle sensors, and the spatial directions of the light beams are not used in any calculations. To measure the positions of multiple light spots simultaneously, their intensity distribution should be relatively homogenous.

However, the application of this inventive light projection technique is not restricted to this type of angle sensors, implying that other angle sensors, e.g. automatic theodolites can be applied. Such theodolites are usually restricted to measure single light spots, and hence a severely increased data acquisition time would be the result.

To calculate the spatial coordinates of a point using triangulation algorithms, two spatial directions must be measured from known global positions, e.g. by using two angle sensors. The spatial directions of the diffracted beams are not sufficiently precise to be used as one of the required directions.

Even though the description above and the following claims are concentrated on the use of optical fibre gratings, the claims should be considered as including technically equivalent means, like conventional diffraction gratings and modifications of such gratings, and holographic gratings. Furthermore, where the description and patent claims describes the use of a mirror to redirect the laser beam in a scanning system, this should be considered as including technically equivalent mechanical, mechano-optical or acousto-optical means.

Various system configurations based on the present inventions have been described above. These configurations cover a variety of industrial and laboratory applications.

An example of measuring the coordinates of separate light sources is for rigging and alignment applications. Dynamic measurements can be applied to measure oscillations or vibrations of mechanical structures. As a function of optimal location of each light source, observations of their mutual movements give information on the vibrational modes of the structure.

The following list shows examples of static or dynamic measurements of the spatial position and orientation of objects:

- model movements in wind tunnels or hydrodynamic laboratories, or other similar applications where high precision is required,
- relative positioning of two objects (docking), e.g. a robot arm and a work piece,
- input for guidance of automated guided vehicles in production and storage facilities.

Profile measurements are used for quality control of curved parts manufactured mainly in automotive and aerospace industry. The present use of mechanical coordinate measuring machines has certain limitations, and hence, there is a demand for accurate non-contact measurement systems. The following are the most important applications:

- quality control of curved parts manufactured by the use of numerically controlled milling machines, or in a sheet metal stamping process,
- quality control and deformation inspections of stamping tools,
- digitization of surfaces, e.g. in aesthetic or aerodynamic modelling of new products, either in model or full scale.

A complete survey of the geometry of a surface is obtained using a laser scanning system that scans the entire surface. This method is very flexible, as the scanning pattern can be easily adapted to the size and shape of the surface, and the accuracy requirements.

Today, the quality control of stamped products is based on the use of mechanical templates. These are used to check the geometry of the surface at a number of critical points. To every different product, a specific template has to be manufactured. This quality check method is time consuming, thus its use is restricted to spot tests only.

A geometry measurement system based on a system for projecting multiple point sized spots as suggested above, replaces the use of these templates completely The essential data is the deviation of the actual surface profile from nominal values in certain critical check points. The present system can handle all generated light spots simultaneously, and hence give a very fast presentation of such deviations. The nominal values are read directly from the CAD base.

One projection system including dual gratings can generate about 1000 light spots as checkpoints across a surface. The pattern density can be further increased using multiple projection systems. The survey of a surface is completed within seconds. Such a system can replace the present use of templates in automotive industry, and allow for 100 % control of all manufactured parts in a serial production line. This means faster, more reliable and far more flexible solutions. A system can easily be adapted to check another product line, with a different surface curvature, as no manufacturing of new templates is required.

For some applications a single grating, generating a line of light spots across a surface, is adequate. An example is quality control of car bumper curvature.

If a very small number of check points are needed, these points can be illuminated using stationary laser sources without gratings, directed towards the surface.

Using the solutions as suggested, improved product quality is obtained, due to more frequent and reliable controls and due to the feasibility of controlling beyond the reach of existing techniques. The pay-off of the system is very good, due to its competitive price and broader applicability than existing systems.

For most applications the measurement system needs to be transported to the site of the object to be measured, e.g. in a production line or at the plant of a subsupplier. This means that all hardware must be easily transportable, and its operation should not depend on fixed angle sensor positions. The system according to the present invention does not require a dedicated measurement laboratory. Furthermore, the system can be designed for industrial environment.

Claims

1. An opto-electronic angle sensor means (28) for measuring spatial directions towards point sized light sources (10) or reflecting points illuminated by a discrete light source, said sensor means comprising an angle sensor having a spherical lens (2) and a two-dimensional array (3) of photo-sensitive elements (11),

   characterised in that the sensor means further comprises:

   image processing means (29) operable to compute the spatial direction of said light sources or illuminated reflecting points from the uncorrected position of an image (12) of said light sources or illuminated reflecting points (10) as registered in the local coordinate system of said array (3) of photosensitive elements (11),

   said image processing means including a two-dimensional calibration table relating said uncorrected position in said local coordinate system to the angles defining spatial directions, the calibration table being generated by a single calibration provided by means operable to determine the center of rotational symmetry of the angle sensor lens (2) and determine the geometrical errors of the sensor means to provide the relationship between the spatial directions and a position of the image (12) on the photosensitive array (3), and

   said image processing means (29) having means for effecting statistical analysis of the intensity distribution by correcting and comparing said intensity values registered by multiple neighbouring photosensitive elements (11) for increasing the resolution and accuracy of the angle measurement which are otherwise limited by the size of said photosensitive elements (11).

2. A method relating to an opto-electronic angle sensor (28) for measuring spatial directions towards point sized light sources (10) or reflecting points illuminated by a light source, said sensor comprising a spherical lens (2) and a two-dimensional array (3) of photosensitive elements (11),

   characterised in that the method comprises the steps of:

   effecting a single calibration enabling said angle sensor (28) to be used at various locations without requiring any recalibration, the calibration step comprising:

   determining the centre of rotational symmetry (7) of the angle sensor lens (2), by correction of the position of an adjustable mounting fixture (4) attached to the angle sensor in a position corresponding to the rotational axes (6) of said sensor, such that if the lens optical axis (5) is defined as the x axis, the z axis of the angle sensor is defined by the vertical symmetry axis of said mounting fixture (4) and the y axis is defined by its orthogonality to said x and z axes, by defining rotations around the z axis as horizontal angles and rotations around the y axis as vertical angles, by mounting the angle sensor onto a rotary table (13) and levelling to ensure that the optical axis is horizontal, by mounting a minimum of two light sources (14, 15) at approximately the same level as the optical axis (5), such that a straight line can be drawn through the two light sources and the rotational axis of the rotary table (13), and by adjusting the mount (4) of the angle sensor to the rotary table until the images of the two light sources

are over-lapping, whatever is the rotary position of the angle sensor, and clamping said mounting fixture to the angle sensor in this position,

calibrating said angle sensor (28) for measurement of angles relative to said two rotational axes, by using a substantially vertically mounted linear device comprising light source means in the form of either an array of light sources (25,26,27) or illuminated reflecting points or an illuminated string or slit (16), said linear device having a length corresponding to the field of view of the angle sensor in one dimension, by levelling the angle sensor such that one of its rotational axes is exactly vertical, by having said linear device mounted parallel to said rotational axis, and

either having said angle sensor mounted on a high position rotary table (13) so that one of said rotational axes further is parallel and coincides with the rotational axis of the rotary table, and step-wise rotating the angle sensor while the image of the linear device and the corresponding rotary table angle are simultaneously registered for every step,

or by step-wise moving said linear device in a known direction crossing the sensor optical axis (5), and registering the horizontal position of said linear array of light sources or reflecting points and its corresponding image simultaneously,

thereby to determine the relation between the angle and the position of the image on the photo sensitive array; and

repeating this procedure for the second rotational axis of the angle sensor, followed by processing of all data to establish a two-dimensional calibration table relating image coordinates to spatial direction given as horizontal and vertical angles,

said calibration being based on using light source means having well defined and known spectral distribution, and

statistically analysing values of intensity registered by multiple neighbouring photosensitive elements to increase the resolution and accuracy of the angle measurements which are otherwise limited by the size of said photosensitive elements.

3. The method as claimed in claim 2, characterised in:

that said calibration is based on mounting said linear device such that only a small part of the vertical field of view is covered by the length of the device, and that only a fraction of the field of view of the angle sensor (28) can be calibrated having the angle sensor levelled, and

that the rest of the vertical field of view of the angle sensor is calibrated using a mounting fixture (21,23) allowing the angle sensor to be tilted step-wise around an axis which is normal to the optical axis, so that in each tilted position a part of the photosensitive array is calibrated, and the tilt angle is measured to be used for computation of the relation between the observed image coordinates and the spatial angle.

4. A system for opto-electronic measurements of spatial coordinates of one or multiple light point sources or reflecting points (35) illuminated by one or multiple light sources in a 3-dimensional spatial co-ordinate system having three axes, characterised in that it comprises

at least two angle sensors (28a,b), each angle sensor having a spherical lens and a two-dimensional array (3) of photosensitive elements (11) such that the angle sensors are adapted to provide an image (12) of the light point sources or illuminated reflected points (35) as registered in local coordinates of the array of photosensitive elements,

a plurality of dedicated image processing units (29), each unit processing the image registered by each respective angle sensor to two-dimensional angular values for each light source or illuminated point, and having means for effecting statistical analysis of the intensity distribution by collecting and comparing said intensity values registered by multiple neighbouring photosensitive elements (11) for increasing the resolution and accuracy of the angle measurements which are otherwise limited by the size of said photosensitive elements (11), and

a data processor (30) operable to compute the coordinates of each light source or illuminated point, said data processor including means for obtaining the relationship between the internal coordinate systems of the individual angle sensors and the spatial coordinate system, the dataprocessor carrying out one of the following operations:

by said angle sensors being aligned parallel to one of the said axes and located in known positions, and their orientations calculated from the measured spatial directions to a light source or an illuminated point (41) which is located in a known position and thereby constituting a common reference point,

by said data processor calculating the positions and orientations of the angle sensors on the basis of measured directions to at least three light point sources (38,39,40) in known

spatial coordinates,

by said data processor calculating the positions and orientations of the angle sensors on the basis of measured directions to a minimum number of six light points, where the mutual separation distance is known for at least two thereof.

5. System for opto-electronic measurements as claimed in claim 4, wherein each angle sensor (28) measures spatial directions towards point sized light sources (35) or reflecting points illuminated by a light source, each angle sensor (28) having a spherical lens (2) and a two dimensional array (3) of photosensitive elements (11) and further comprises:

means (29) for computing a spatial direction of said light sources (35) or illuminated points from the position of the image (12) or said light sources or illuminated points as registered in the local coordinates of said array (3) of photosensitive elements, said means for computing including a two dimensional calibration table that is generated by a single calibration that allows the angle sensor to be used in various locations without requiring recalibration, said calibration resulting from a determination of the center (7) of rotational symmetry of the angle sensor lens (2), and a determination of the relation between the spatial directions and the position of the image on the photosensitive array by the use of a high precision angle reference wherein said calibration table is obtained using light sources having a well defined and known spectral distribution, and

means (29) for performing a statistical analysis of the intensity values registered by multiple neighbouring photosensitive elements for measuring that resolution and accuracy of the angle measurements.

6. System as claimed in claim 4 or 5, in which the light point sources are movable, said system characterised in:

that the date processor (30) comprises means for computing the dynamic behaviour of the coordinated of each light source or illuminated point relative to a ground fixed coordinate system, or relative to each other.

7. System as claimed in any one of claims 4-6, characterised in:

that the system comprises a number of point sized light sources (38,39,40) and a power supply for said light sources, that at least three of said light sources are attached to each of a number of objects (42), such that the positions of said light sources are known in object oriented local coordinate system and

that the data processor (30) comprises means to compute the position and orientation of each object (42) relative to a ground fixed coordinate system or relative to each other, based on the measured global coordinates of each light source.

8. System as claimed in any one of claims 4-6, characterised in:

that the system comprises means (33,34) to illuminate a surface (36) point by point, and that the data processor includes means to store a set of coordinates corresponding to points on a surface, and means to use these coordinates to describe the geometry of the surface.

9. System as claimed in any one of claims 4-6, characterised in:

that said system comprises a number of light sources (43,44,45) pointing in fixed directions to illuminate a corresponding number of points (46,47,48) on an object or a surface 36), and that the data processor (30) includes means to calculate the coordinates of the illuminated points and to compare them to nominal values.

10. System as claimed in any one of claims 4-6, characterised in:

that the system includes means to illuminate the surface point by point, comprising a directed light source (55) emitting a light beam (57), a diffraction grating (49), and focusing optics (56) to obtain a pattern of well defined discrete point sized light spots (58) forming a curved line across the surface (36).

11. System as claimed in any one of claims 4-6, characterised in:

that the system includes means to illuminate the surface point by point, comprising a directed light source (55) emitting a light beam (57), two diffraction gratings (49,59), each dividing an incident light beam to multiple light beams and mounted together such that the two gratings are orthogonal, and focusing optics (56) to obtain a two-dimensional pattern of discrete point sized spots (58) onto the surface (36).

12. System as claimed in any one of claims 4-6, characterised in:

that the system includes means to illuminate the surface point by point, comprising a directed light source (55) emitting a light beam, a diffraction grating (49), and focusing

optics (56) to obtain a pattern of well defined discrete point sized light spots (58) forming a curved line across the surface (36), and

that the system includes a single axis rotary mirror (34) to move the line of projected light spots across the surface in a direction orthogonal to the direction of said line of light spots.

13. Opto-electronic system for measuring spatial coordinates of points located on a surface as claimed in any one of claims 10-12, characterised in:

that the system includes a data processor (30) capable of describing the geometry of the surface (36) on the basis of the measured coordinated values for a plurality of illuminated points (58).

14. Opto-electronic system for measuring spatial coordinates of points located on a surface as claimed in any one of claims 10-12, characterised in:

that the system includes a data processor (30) designed to compare the measured spatial coordinates for each illuminated point (58) to nominal values.

Patentansprüche

1. Ein opto-elektronisches Winkel-Meßwertgebermittel (28), um Raumrichtungen zu punktförmigen Lichtquellen (10) oder reflektierenden Punkten, die durch eine einzelne Lichtquelle beleuchtet werden, zu messen, wobei das Meßwertgebermittel einen Winkel-Meßwertgeber mit einer sphärischen Linse (2) und einem zweidimensionalen Feld (3) lichtempfindlicher Elemente (11) umfaßt,
dadurch gekennzeichnet, daß das Meßwertgebermittel weiter umfaßt:
Bildverarbeitungsmittel (29), das die Baumrichtung der Lichtquellen oder beleuchteten reflektierenden Punkte aus der nicht korrigierten Position eines Bildes (12) der Lichtquellen oder beleuchteten reflektierenden Punkte (10), wie in dem lokalen Koordinatensystem des Feldes (3) lichtempfindlicher Elemente (11) angezeigt wird, berechnen kann,
wobei das Bildverarbeitungsmittel eine zweidimensionale Kalibrierungstabelle einschließt, welche die nicht korrigierte Position in dem lokalen Koordinatensystem mit den Winkeln, die die Raumrichtungen definieren, in Zusammenhang bringt, wobei die Kalibrierungstabelle durch eine einzelne Kalibrierung erzeugt wird, welche durch ein Mittel ausgeführt wird, das die Mitte einer Rotationssymmetrie der Linse (2) des Winkel-Meßwertgebers bestimmen kann und die geometrischen Fehler des Meßwertgebermittels bestimmen kann, um die Beziehung zwischen den Raumrichtungen und einer Position des Bildes (12) auf dem lichtempfindlichen Feld (3) zu liefern, und
wobei das Bildverarbeitungsmittel (29) Mittel aufweist, um eine statistische Analyse der Intensitätsverteilung auszuführen, indem die Intensitätswerte, die durch mehrere benachbarte lichtempfindliche Elemente (11) angezeigt werden, korrigiert und verglichen werden, um die Auflösung und Genauigkeit der Winkelmessung zu erhöhen, die andernfalls durch die Größe der lichtempfindlichen Elemente (11) begrenzt sind.

2. Ein Verfahren, das sich auf einen opto-elektronischen Winkel-Meßwertgeber (28) bezieht, um Raumrichtungen zu punktförmigen Lichtquellen (10) oder reflektierenden Punkten, die durch eine Lichtquelle beleuchtet werden, zu messen, wobei der Meßwertgeber eine sphärische Linse (2) und ein zweidimensionales Feld (3) lichtempfindlicher Elemente (11) enthält,
dadurch gekennzeichnet, daß das Verfahren die Schritte umfaßt, daß:
eine einzelne Kalibrierung ausgeführt wird, die ermöglicht, daß der Winkel-Meßwertgeber (28) an verschiedenen Stellen verwendet wird, ohne irgendeine Neu-Kalibrierung zu erfordern, wobei der Kalibrierungsschritt umfaßt, daß:
die Mitte einer Rotationssymmetrie (7) der Linse (2) des Winkel-Meßwertgebers durch eine Korrektur der Position einer einstellbaren Gestell-Befestigungsvorrichtung (4), die an dem Winkel-Meßwertgeber an einer Position, welche den Rotationsachsen (6) des Meßwertgebers entspricht, angebracht ist, derart bestimmt wird, daß, falls die optische Achse (5) der Linse als die x-Achse definiert wird, die z-Achse des Winkel-Meßwertgebers durch die vertikale Symmetrieachse der Gestell-Befestigungsvorrichtung (4) definiert wird und die y-Achse durch ihre Orthogonalität zu den x- und z-Achsen definiert wird, indem Rotationen um die z-Achse herum als horizontale Winkel und Rotationen um die y-Achse herum als vertikale Winkel definiert werden, indem der Winkel-Meßwertgeber auf einem Drehtisch (13) befestigt und ausgerichtet wird, um sicherzustellen, daß die optische Achse horizontal verläuft, indem ein Minimum von zwei Lichtquellen (14,15) bei annähernd der gleichen Ebene wie die optische Achse (5) derart befestigt wird, daß eine gerade Linie durch die zwei Lichtquellen und die horizontale Achse des Drehtisches (13) gezogen werden kann, und indem

das Gestell (4) des Winkel-Meßwertgebers an dem Drehtisch eingestellt wird, bis die Bilder der zwei Lichtquellen überlappen, was auch immer die Drehposition des Winkel-Meßwertgebers ist, und die Gestell-Befestigungsvorrichtung an dem Winkel-Meßwertgeber in dieser Position festgeklemmt wird,
der Winkel-Meßwertgeber (28) für eine Messung von Winkeln relativ zu den zwei Rotationsachsen kalibriert wird, indem eine im wesentlichen vertikal befestigte lineare Vorrichtung verwendet wird, die ein Lichtquellenmittel in der Form von entweder einem Feld von Lichtquellen (25, 26, 27) oder beleuchteten reflektierenden Punkten oder einen beleuchteten Faden oder Schlitz (16) umfaßt, wobei die lineare Vorrichtung eine Länge besitzt, die dem Sichtfeld des Winkel-Meßwertgebers in einer Dimension entspricht, indem der Winkel-Meßwertgeber derart ausgerichtet wird, daß eine seiner Rotationsachsen exakt vertikal verläuft, indem die lineare Vorrichtung parallel zu der Rotationsachse befestigt wird, und
entweder der Winkel-Meßwertgeber auf einem Drehtisch (13) in einer hohen Position befestigt wird, so daß eine der Rotationsachsen weiter parallel verläuft und mit der Rotationsachse des Drehtisches zusammenfällt, und der Winkel-Meßwertgeber schrittweise gedreht wird, während das Bild der linearen Vorrichtung und der entsprechende Drehtisch-Winkel gleichzeitig für jeden Schritt angezeigt werden,
oder die lineare Vorrichtung in einer bekannten Richtung, welche die optische Achse (5) des Meßwertgebers kreuzt, schrittweise bewegt wird und die horizontale Position des linearen Feldes von Lichtquellen oder reflektierenden Punkten und ihr entsprechendes Bild gleichzeitig angezeigt werden,
um dadurch die Beziehung zwischen dem Winkel und der Position des Bildes auf dem lichtempfindlichen Feld zu bestimmen; und
dieses Verfahren für die zweite Rotationsachse des Winkel-Meßwertgebers wiederholt wird, gefolgt von einem Verarbeiten aller Daten, um eine zweidimensionale Kalibrierungstabelle zu erstellen, die Bildkoordinaten mit einer Raumrichtung, die als horizontale und vertikale Winkel gegeben ist, zu verbinden,
wobei die Kalibrierung auf eine Verwendung eines Lichtquellenmittels mit einer wohldefinierten und bekannten spektralen Verteilung gestützt wird, und
Werte einer Intensität, welche durch mehrere benachbarte lichtempfindliche Elemente angezeigt werden, statistisch analysiert werden, um die Auflösung und Genauigkeit der Winkelmessungen zu erhohen, die andernfalls durch die Größe der lichtempfindlichen Elemente begrenzt sind.

3. Ein Verfahren nach Anspruch 2,
dadurch gekennzeichnet:
daß die Kalibrierung auf einer Befestigung der linearen Vorrichtung derart beruht, daß nur ein kleiner Teil des vertikalen Sichtfeldes durch die Länge der Vorrichtung bedeckt wird und daß nur ein Bruchteil des Sichtfeldes des Winkel-Meßwertgebers (28) mit dem ausgerichteten Winkel-Meßwertgeber kalibriert werden kann, und
daß der Rest des vertikalen Sichtfeldes des Winkel-Meßwertgebers unter Verwendung einer Gestell-Befestigungsvorrichtung (21, 23) kalibriert wird, die gestattet,
daß der Winkel-Meßwertgeber schrittweise um eine Achse herum geneigt wird, welche senkrecht zu der optischen Achse verläuft, so daß in jeder geneigten Position ein Teil des lichtempfindlichen Feldes kalibriert wird und der Neigungswinkel gemessen wird, um für eine Berechnung der Beziehung zwischen den beobachteten Bildkoordinaten und dem Raumwinkel verwendet zu werden.

4. Ein System für opto-elektronische Messungen von Raumkoordinaten von einer oder mehreren Lichtpunktquellen oder reflektierenden Punkten (35), die durch eine oder mehrere Lichtquellen beleuchtet werden, in einem dreidimensionalen Raumkoordinatensystem mit drei Achsen, dadurch gekennzeichnet, daß es umfaßt
mindestens zwei Winkel-Meßwertgeber (28a,b), wobei jeder Winkel-Meßwertgeber eine sphärische Linse und ein zweidimensionales Feld (3) lichtempfindlicher Elemente (11) besitzt, so daß die Winkel-Meßwertgeber ein Bild (12) der Lichtpunktquellen oder beleuchteten reflektierenden Punkte (35) liefern können, wie in lokalen Koordinaten des Feldes lichtempfindlicher Elemente angezeigt wird,
eine Vielzahl zugeordneter Bildverarbeitungseinheiten (29), wobei jede Einheit das Bild, welches durch jeden jeweiligen Winkel-Meßwertgeber angezeigt wird, in zweidimensionale Winkelwerte für jede Lichtquelle oder jeden beleuchteten Punkt verarbeitet und Mittel besitzt, um eine statistische Analyse der Intensitätsverteilung auszuführen, indem die Intensitätswerte, die durch mehrere benachbarte lichtempfindliche Elemente (11) angezeigt werden, korrigiert und verglichen werden, um die Auflösung und Genauigkeit der Winkelmessungen zu erhöhen, die andernfalls durch die Größe der lichtempfindlichen Elemente (11) begrenzt sind, und

eine Datenverarbeitungsvorrichtung (30), welche die Koordinaten jeder Lichtquelle oder jedes beleuchteten Punktes berechnen kann, wobei die Datenverarbeitungsvorrichtung Mittel einschließt, um die Beziehung zwischen den internen Koordinatensystemen der einzelnen Winkel-Meßwertgeber und dem Raumkoordinatensystem zu erhalten, wobei die Datenverarbeitungsvorrichtung eine der folgenden Operationen ausführt:

daß die Winkel-Meßwertgeber parallel mit einer der Achsen ausgerichtet und an bekannten Positionen angeordnet und ihre Orientierungen aus den gemessenen Raumrichtungen zu einer Lichtquelle oder einem beleuchteten Punkt (41) berechnet werden, die oder der an einer bekannten Position angeordnet ist und dadurch einen allgemeinen Referenzpunkt bildet,

daß die Datenverarbeitungsvorrichtung die Positionen und Orientierungen der Winkel-Meßwertgeber auf der Grundlage gemessener Richtungen zu mindestens drei Lichtpunktquellen (38, 39, 40) an bekannten Raumkoordinaten berechnet,

daß die Datenverarbeitungsvorrichtung die Positionen und Orientierungen der Winkel-Meßwertgeber auf der Grundlage gemessener Richtungen zu einer Minimalanzahl von sechs Lichtpunkten berechnet, wobei der gegenseitige Separationsabstand für mindestens zwei davon bekannt ist.

5. System für opto-elektronische Messungen nach Anspruch 4, worin jeder Winkel-Meßwertgeber (28) Raumrichtungen zu punktförmigen Lichtquellen (35) oder reflektierenden Punkten, die durch eine Lichtquelle beleuchtet werden, mißt, wobei jeder Winkel-Meßwertgeber (28) eine sphärische Linse (2) und ein zweidimensionales Feld (3) lichtempfindlicher Elemente (11) aufweist und weiter umfaßt:

Mittel (29), um eine Raumrichtung der Lichtquellen (35) oder beleuchteten Punkte aus der Position des Bildes (12) oder der Lichtquellen oder beleuchteten Punkte, wie in den lokalen Koordinaten des Feldes (3) lichtempfindlicher Elemente angezeigt wird, zu berechnen, wobei das Mittel zum Berechnen eine zweidimensionale Kalibrierungstabelle einschließt, die durch eine einzelne Kalibrierung erzeugt wird, welche gestattet, daß der Winkel-Meßwertgeber an verschiedenen Stellen verwendet wird, ohne eine Neu-Kalibrierung zu erfordern, wobei sich die Kalibrierung aus einer Bestimmung der Mitte (7) einer Rotationssymmetrie der Linse (2) des Winkel-Meßwertgebers und einer Bestimmung der Beziehung zwischen den Raumrichtungen und der Position des Bildes auf dem lichtempfindlichen Feld durch die Verwendung einer Winkelmessung mit hoher Genauigkeit ergibt, worin die Kalibrierungstabelle unter Verwendung von Lichtquellen, die eine wohldefinierte und bekannte spektrale Verteilung aufweisen, erhalten wird, und

Mittel (29), um eine statistische Analyse der Intensitätswerte, die durch mehrere benachbarte lichtempfindliche Elemente angezeigt werden, durchzuführen, um die Auflösung und Genauigkeit der Winkelmessungen zu messen.

6. System nach Anspruch 4 oder 5, in welchem die Lichtpunktquellen beweglich sind, wobei das System dadurch gekennzeichnet ist:

daß die Datenverarbeitungsvorrichtung (30) Mittel enthält, um das dynamische Verhalten der Koordinaten jeder Lichtquelle oder jedes beleuchteten Punktes relativ zu einem erdgebundenen Koordinatensystem oder relativ zu einander zu berechnen.

7. System nach irgendeinem der Ansprüche 4 - 6, dadurch gekennzeichnet:

daß das System eine Anzahl von punktförmigen Lichtquellen (38, 39, 40) und eine Energieversorgung für die Lichtquellen enthält, daß mindestens drei der Lichtquellen an jedem einer Anzahl von Objekten (42) derart angebracht sind, daß die Positionen der Lichtquellen in einem objektorientierten lokalen Koordinatensystem bekannt sind, und

daß die Datenverarbeitungsvorrichtung (30) Mittel enthält, um die Position und Orientierung von jedem Objekt (42) relativ zu einem erdgebundenen Koordinatensystem oder relativ zu einander beruhend auf den gemessenen globalen Koordinaten jeder Lichtquelle zu berechnen.

8. System nach irgendeinem der Ansprüche 4 - 6, dadurch gekennzeichnet:

daß das System Mittel (33, 34) enthält, um eine Oberfläche (36) punktweise zu beleuchten, und daß die Datenverarbeitungsvorrichtung Mittel, um einen Satz von Koordinaten, die Punkten auf einer Oberfläche entsprechen, zu speichern, und Mittel einschließt, um diese Koordinaten zur Beschreibung der Geometrie. der Oberfläche zu verwenden.

9. System nach irgendeinem der Ansprüche 4 - 6, dadurch gekennzeichnet:

daß das System eine Anzahl von Lichtquellen (43, 44, 45) enthält, die in fixierte Richtungen weisen, um eine entsprechende Anzahl von Punkten (46, 47, 48) auf einem Objekt oder einer Oberfläche (36) zu beleuchten, und daß

die Datenverarbeitungsvorrichtung (30) Mittel einschließt, um die Koordinaten der beleuchteten Punkte zu berechnen und um sie mit Nenn- bzw. Sollwerten zu vergleichen.

10. System nach irgendeinem der Ansprüche 4 - 6, dadurch gekennzeichnet:
daß das System ein Mittel einschließt, um die Oberfläche punktweise zu beleuchten, welches eine gerichtete Lichtquelle (55), die einen Lichtstrahl (57) emittiert, ein Beugungsgitter (49) und eine fokussierende Optik (56) umfaßt, um ein Muster wohldefinierter diskreter punktförmiger Lichtflecken bzw. -punkte (58) zu erhalten, die eine gekrümmte Linie über die Oberfläche (36) bilden.

11. System nach irgendeinem der Ansprüche 4 - 6, dadurch gekennzeichnet:
daß das System ein Mittel einschließt, um die Oberfläche punktweise zu beleuchten, welches eine gerichtete Lichtquelle (55), die einen Lichtstrahl (57) emittiert, zwei Beugungsgitter (49, 59), die jeweils einen einfallenden Lichtstrahl in mehrere Lichtstrahlen teilen und zusammen derart befestigt sind, daß die zwei Gitter orthogonal sind, und eine fokussierende Optik (56) umfaßt, um ein zweidimensionales Muster diskreter punktförmiger Lichtpunkte (58) auf der Oberfläche (36) zu erhalten.

12. System nach irgendeinem der Ansprüche 4 - 6, dadurch gekennzeichnet:
daß das System ein Mittel einschließt, um die Oberfläche punktweise zu beleuchten, welches eine gerichtete Lichtquelle (55), die einen Lichtstrahl emittiert, ein Beugungsgitter (49) und eine fokussierende Optik (56) umfaßt, um ein Muster wohldefinierter diskreter puntförmiger Lichtpunkte (58), die eine gekrümmte Linie über die Oberfläche (36) bilden, zu erhalten, und
daß das System einen einachsigen Drehspiegel (34) einschließt, um die Linie projizierter Lichtpunkte über die Oberfläche in einer Richtung orthogonal zu der Richtung der Linie von Lichtpunkten zu bewegen.

13. Opto-elektronisches System, um Raumkoordinaten von auf einer Oberfläche gelegenen Punkten zu messen, nach irgendeinem der Ansprüche 10 - 12, dadurch gekennzeichnet:
daß das System eine Datenverarbeitungsvorrichtung (30) einschließt, die in der Lage ist, die Geometrie der Oberfläche (36) auf der Grundlage der gemessenen Koordinatenwerte für eine Vielzahl beleuchteter Punkte (58) zu beschreiben.

14. Opto-elektronisches System, um Raumkoordinaten von auf einer Oberfläche gelegenen Punkten zu messen, nach irgendeinem der Ansprüche 10 - 12, dadurch gekennzeichnet:
daß das System eine Datenverarbeitungsvorrichtung (30) einschließt, die ausgelegt ist, um die gemessenen Raumkoordinaten für jeden beleuchteten Punkt (58) mit Nenn- bzw. Sollwerten zu vergleichen.

Revendications

1. Moyen capteur d'angle opto-électronique (28) pour mesurer des directions spatiales vers des sources lumineuses de dimension ponctuelle (10) ou des points de réflexion éclairés par une source lumineuse discrète, ledit moyen capteur comprenant un capteur d'angle comportant une lentille sphérique (2) et un réseau bidimensionnel (3) d'éléments photosensibles (11),
caractérisé en ce que ce moyen capteur comprend en outre :
un moyen de traitement d'image (29) pouvant être mis en fonctionnement pour calculer la direction spatiale desdites sources lumineuses ou desdits points de réflexion éclairés à partir de la position non corrigée d'une image (12) desdites sources lumineuses ou desdits points de réflexion éclairés (10) telle qu'enregistrée dans le système de coordonnées locales dudit réseau (3) des éléments photosensibles (11),
ledit moyen de traitement d'image incluant une table d'étalonnage bidimensionnelle mettant en relation ladite position non corrigée dans ledit système de coordonnées locales avec les angles définissant des directions spatiales, la table d'étalonnage étant générée par un seul étalonnage obtenu par un moyen pouvant être mis en fonctionnement pour déterminer le centre de symétrie de rotation de la lentille (2) du capteur d'angle et pour déterminer les erreurs géométriques du moyen capteur afin d'obtenir la relation qui existe entre les directions spatiales et une position de l'image (12) sur le réseau photosensible (3), et,
ledit moyen de traitement d'image (29) comportant un moyen pour effectuer une analyse statistique de la répartition de l'intensité par correction et comparaison desdites valeurs d'intensité enregistrées par plusieurs éléments photosensibles (11) proches afin d'augmenter la résolution et la précision de la mesure d'un angle qui autrement sont limitées par les dimensions desdits éléments photosensibles (11).

2. Procédé relatif à un capteur d'angle opto-électronique (28) pour mesurer des directions spatiales vers des sources lumineuses de dimension ponctuelle (10) ou des points de réflexion éclairés par une source lumineuse, ledit capteur comprenant une lentille sphérique (2) et un réseau bidimensionnel (3) d'éléments photosensibles (11),

caractérisé en ce que ce procédé comprend les étapes qui consistent à :

effectuer un seul étalonnage permettant d'utiliser ledit capteur d'angle (28) à différents endroits sans nécessiter un réétalonnage, l'étape d'étalonnage consistant à :

déterminer le centre de symétrie (7) de rotation de la lentille (2) du capteur d'angle, par correction de la position d'un support réglable (4) fixé au capteur d'angle à une position correspondant aux axes de rotation (6) dudit capteur, telle que, si l'axe optique (5) de la lentille est défini en tant qu'axe x, l'axe z du capteur d'angle est défini par l'axe de symétrie vertical dudit support (4) et l'axe y est défini par son orthogonalité par rapport auxdits axes x et z, par définition des rotations autour de l'axe z comme des angles horizontaux et des rotations autour de l'axe y comme des angles verticaux, par montage du capteur d'angle sur un plateau tournant (13) et réglage du niveau afin de garantir que l'axe optique est horizontal, par montage d'un minimum de deux sources lumineuses (14, 15) approximativement au même niveau que l'axe optique (5), tel qu'une ligne droite peut être tracée entre les deux sources lumineuses et l'axe de rotation du plateau tournant (13), et par réglage du support (4) du capteur d'angle par rapport au plateau tournant jusqu'à ce que les images des deux sources lumineuses se recouvrent, quelle que soit la position de rotation du capteur d'angle, et fixation dudit support au capteur d'angle à cette position,

étalonner ledit capteur d'angle (28) pour la mesure d'angles par rapport auxdits deux axes de rotation, par utilisation d'un dispositif linéaire monté sensiblement verticalement comprenant un moyen à sources lumineuses sous la forme soit d'un réseau de sources lumineuses (25, 26, 27), soit de points de réflexion éclairés, soit d'un cordon ou d'une fente éclairée (16), ledit dispositif linéaire ayant une longueur correspondant au champ de perception du capteur d'angle dans une dimension, par réglage du niveau du capteur d'angle tel qu'un de ses axes de rotation soit exactement vertical, par montage dudit dispositif linéaire parallèlement audit axe de rotation, et,

soit monter ledit capteur d'angle sur un plateau tournant (13) à une position élevée, de telle sorte qu'un desdits axes de rotation est en outre parallèle à et coïncide avec l'axe de rotation du plateau tournant, et tourner pas-à-pas le capteur d'angle tandis que l'image du dispositif linéaire et l'angle du plateau tournant correspondant sont enregistrés simultanément à chaque pas,

soit déplacer pas-à-pas ledit dispositif linéaire dans une direction connue coupant l'axe optique (5) du capteur, et enregistrer simultanément la position horizontale dudit réseau linéaire des sources lumineuses ou des points de réflexion et son image correspondante,

pour déterminer ainsi la relation qui existe entre l'angle et la position de l'image sur le réseau photosensible ; et,

répéter cette procédure pour le second axe de rotation du capteur d'angle, suivie par le traitement de toutes les données pour établir une table d'étalonnage bidimensionnelle reliant des coordonnées d'image à une direction spatiale donnée par un angle horizontal et un angle vertical,

ledit étalonnage étant basé sur l'utilisation d'un moyen à sources lumineuses ayant une répartition spectrale bien définie et connue, et,

analyser statistiquement les valeurs d'intensité enregistrées par plusieurs éléments photosensibles proches pour augmenter la résolution et la précision des mesures d'angle qui autrement sont limitées par la taille desdits éléments photosensibles.

3. Procédé selon la revendication 2,

caractérisé en ce que :

ledit étalonnage est basé sur le montage dudit dispositif linéaire tel qu'une petite partie seulement du champ de perception vertical est couverte par la longueur du dispositif, et qu'une fraction seulement du champ de perception du capteur d'angle (28) peut être étalonnée en ayant réglé le niveau du capteur d'angle, et,

le reste du champ de perception vertical du capteur d'angle est étalonné en utilisant un support (21, 23) permettant d'incliner pas-à-pas le capteur d'angle autour d'un axe qui est perpendiculaire à l'axe optique, de telle sorte qu'à chaque position inclinée, une partie du réseau photosensible est étalonnée, et l'angle d'inclinaison est mesuré pour servir au calcul de la relation qui existe entre les coordonnées de l'image observée et l'angle spatial.

4. Système pour effectuer des mesures opto-électroniques des coordonnées spatiales d'une ou de plusieurs sources lumineuses ponctuelles

ou de points de réflexion (35) éclairés par une ou plusieurs sources lumineuses dans un système de coordonnées spatiales à 3 dimensions comportant trois axes, caractérisé en ce qu'il comprend :

au moins deux capteurs d'angle (28a, b), chaque capteur d'angle comportant une lentille sphérique et un réseau bidimensionnel (3) d'éléments photosensibles (11) tels que les capteurs d'angle sont adaptés pour fournir une image (12) des sources lumineuses ponctuelles ou des points de réflexion (35) éclairés telle qu'enregistrée sous forme de coordonnées locales du réseau d'éléments photosensibles,

une pluralité d'unités de traitement d'image (29) spécialisées, chaque unité traitant l'image enregistrée par chaque capteur d'angle respectif en valeurs angulaires bidimensionnelles pour chaque source lumineuse ou point éclairé, et comportant un moyen pour effectuer une analyse statistique de la répartition de l'intensité par correction et comparaison desdites valeurs d'intensité enregistrées par plusieurs éléments photosensibles (11) proches afin d'augmenter la résolution et la précision des mesures d'angle qui sont limitées autrement par les dimensions des éléments photosensibles (11), et,

une unité de traitement de données (30) pouvant être mise en fonctionnement pour calculer les coordonnées de chaque source lumineuse ou point éclairé, ladite unité de traitement de données incluant un moyen pour obtenir la relation qui existe entre les systèmes de coordonnées internes des capteurs d'angle individuels et le système de coordonnées spatiales, l'unité de traitement de données exécutant une des opérations suivantes :

par lesdits capteurs d'angle qui sont alignés parallèlement à un desdits axes et placés à des positions connues, et leurs orientations qui sont calculées à partir des directions spatiales mesurées vers une source lumineuse ou un point éclairé (41) situé à une position connue et constituant ainsi un point de référence commun,

par ladite unité de traitement de données qui calcule les positions et les orientations des capteurs d'angle sur la base de directions mesurées vers au moins trois sources lumineuses ponctuelles (38, 39, 40) en coordonnées spatiales connues,

par ladite unité de traitement de données qui calcule les positions et les orientations des capteurs d'angle sur la base de directions mesurées vers un nombre minimal de six points lumineux, où la distance de séparation mutuelle est connue pour au moins deux d'entre eux.

5. Système pour effectuer des mesures optoélectroniques selon la revendication 4, dans lequel chaque capteur d'angle (28) mesure des directions spatiales vers des sources lumineuses de dimension ponctuelle (35) ou des points de réflexion éclairés par une source lumineuse, chaque capteur d'angle (28) comportant une lentille sphérique (2) et un réseau bidimensionnel (3) d'éléments photosensibles (11) et comprend en outre :

un moyen (29) pour calculer une direction spatiale desdites sources lumineuses (35) ou desdits points éclairés à partir de la position de l'image (12) ou desdites sources lumineuses ou points éclairés telle qu'enregistrée sous forme de coordonnées locales dudit réseau (3) des éléments photosensibles, ledit moyen pour calculer incluant une table d'étalonnage bidimensionnelle qui est générée par un seul étalonnage permettant d'utiliser le capteur d'angle à différents endroits sans nécessiter de réétalonnage, ledit étalonnage résultant de la détermination du centre de symétrie (7) de rotation de la lentille (2) du capteur d'angle, et de la détermination de la relation qui existe entre les directions spatiales et la position de l'image sur le réseau photosensible par utilisation d'un angle de référence de haute précision où la table d'étalonnage est obtenue en utilisant des sources lumineuses ayant une répartition spectrale bien définie et connue, et,

un moyen (29) pour effectuer une analyse statistique des valeurs d'intensité enregistrées par plusieurs éléments photosensibles proches afin de mesurer la résolution et la précision des mesures d'angle.

6. Système selon l'une quelconque des revendications 4 et 5, dans lequel les sources lumineuses ponctuelles sont mobiles, ledit système étant caractérisé en ce que :

l'unité de traitement de données (30) comprend un moyen pour calculer le comportement dynamique des coordonnées de chaque source lumineuse ou de chaque point éclairé par rapport à un système de coordonnées fixe de la terre, ou de l'un par rapport à l'autre.

7. Système selon l'une quelconque des revendications 4 à 6, caractérisé en ce que :

le système comprend plusieurs sources lumineuses de dimension ponctuelle (38, 39, 40) et une alimentation en tension pour lesdites sources lumineuses, au moins trois desdites sources lumineuses sont fixées à chacun de plusieurs objets (42), tels que les positions

desdites sources lumineuses sont connues dans un système de coordonnées locales propre à un objet et,

l'unité de traitement de données (30) comprend un moyen pour calculer la position et l'orientation de chaque objet (42) par rapport à un système de coordonnées fixe de la terre ou de l'un par rapport à l'autre, selon les coordonnées globales mesurées de chaque source lumineuse.

8. Système selon l'une quelconque des revendications 4 à 6, caractérisé en ce que :

le système comprend un moyen (33, 34) pour éclairer une surface (36) point par point, et l'unité de traitement de données comprend un moyen pour mémoriser un groupe de coordonnées correspondant à des points sur une surface, et un moyen pour utiliser ces coordonnées afin de décrire la géométrie de la surface.

9. Système selon l'une quelconque des revendications 4 à 6, caractérisé en ce que :

ledit système comprend plusieurs sources lumineuses (43, 44, 45) pointant vers des directions fixes pour éclairer un nombre correspondant de points (46, 47, 48) sur un objet ou une surface (36), et l'unité de traitement de données (30) comprend un moyen pour calculer les coordonnées des points éclairés et les comparer à des valeurs nominales.

10. Système selon l'une quelconque des revendications 4 à 6, caractérisé en ce que :

le système comprend un moyen pour éclairer la surface point par point, comprenant une source lumineuse (55) dirigée émettant un faisceau lumineux (57), un réseau de diffraction (49), et un dispositif optique de focalisation (56) pour obtenir une combinaison de points lumineux de dimension ponctuelle discrets bien définis (58) formant une ligne courbe à travers la surface (36).

11. Système selon l'une quelconque des revendications 4 à 6, caractérisé en ce que :

le système comprend un moyen pour éclairer la surface point par point, comprenant une source lumineuse (55) dirigée émettant un faisceau lumineux (57), deux réseaux de diffraction (49, 59), divisant chacun un faisceau lumineux incident en plusieurs faisceau lumineux et montés ensemble de telle sorte que ces deux réseaux sont orthogonaux, et un dispositif optique de focalisation (56) pour obtenir un motif bidimensionnel de points de dimension ponctuelle discrets (58) sur la surface (36).

12. Système selon l'une quelconque des revendications 4 à 6, caractérisé en ce que :

le système comprend un moyen pour éclairer la surface point par point, comprenant une source lumineuse (55) dirigée émettant un faisceau lumineux, un réseau de diffraction (49), et un dispositif optique de focalisation (56) pour obtenir un motif de points lumineux de dimension ponctuelle discrets bien définis (58) formant une ligne courbe à travers la surface (36), et,

le système comprend un miroir tournant à un seul axe (34) pour déplacer la ligne de points lumineux projetés à travers la surface dans une direction perpendiculaire à la direction de ladite ligne de points lumineux.

13. Système opto-électronique pour mesurer les coordonnées spatiales de points situés sur une surface selon l'une quelconque des revendications 10 à 12, caractérisé en ce que :

le système comprend une unité de traitement de données (30) ayant la capacité de décrire la géométrie de la surface (36) sur la base des valeurs de coordonnées mesurées pour une pluralité de points éclairés (58).

14. Système opto-électronique pour mesurer les coordonnées spatiales de points situés sur une surface selon l'une quelconque des revendications 10 à 12, caractérisé en ce que :

le système comprend une unité de traitement de données (30) conçue pour comparer les coordonnées spatiales mesurées pour chaque point éclairé (58) à des valeurs nominales.

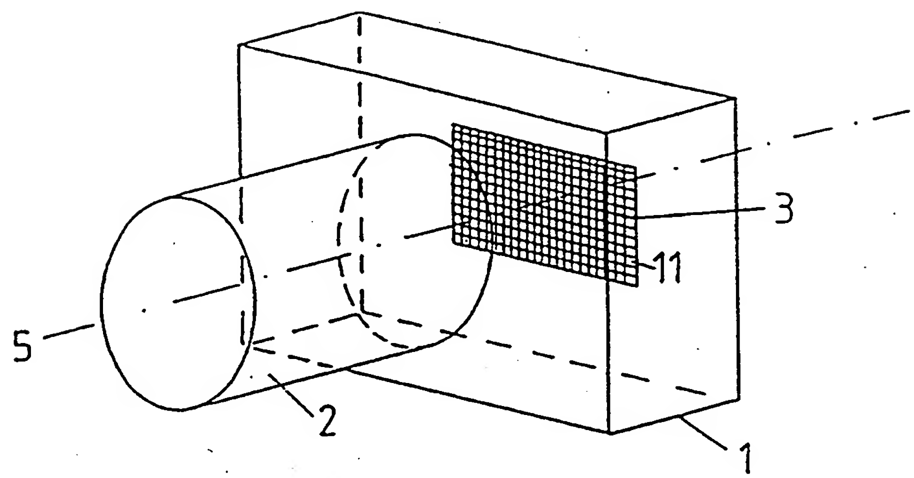


Fig. 1a

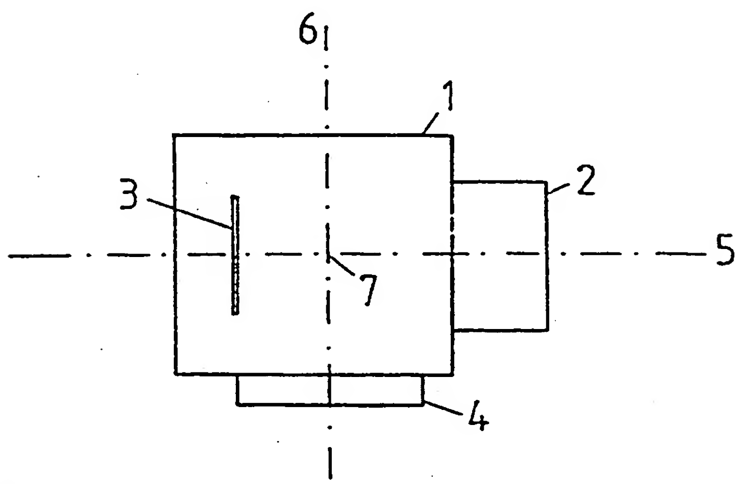


Fig. 1b

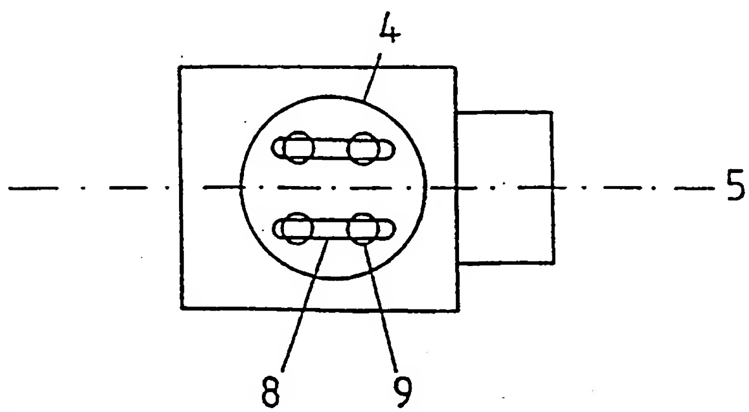


Fig. 1c

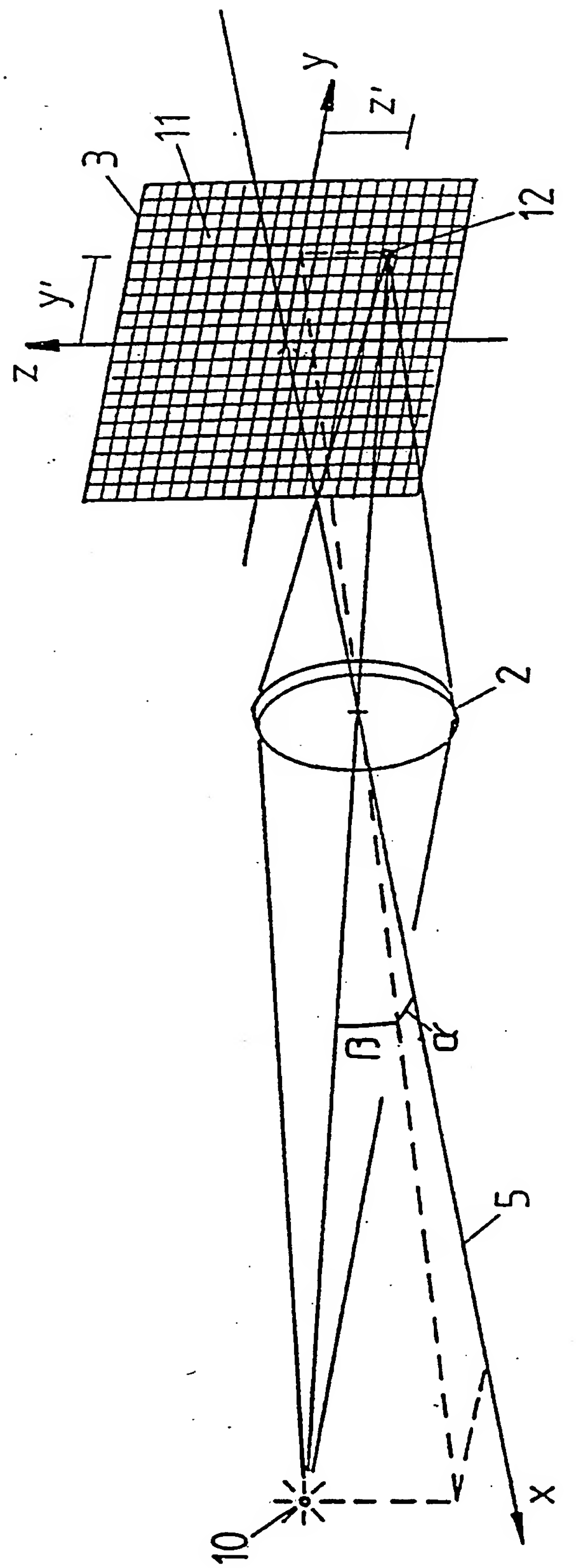


Fig. 2a

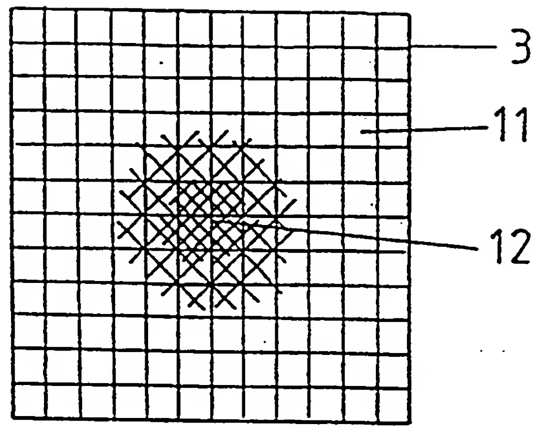


Fig. 2 b

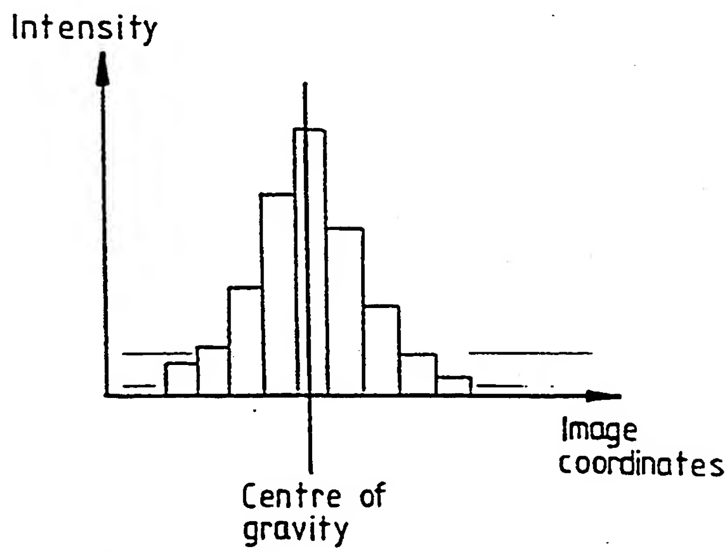


Fig. 2 c

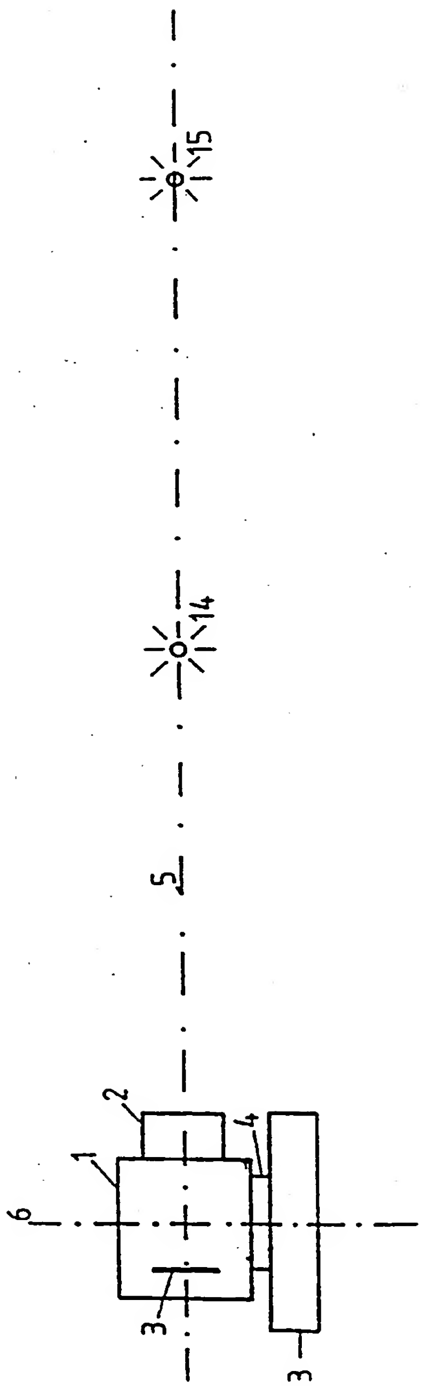


Fig. 3a

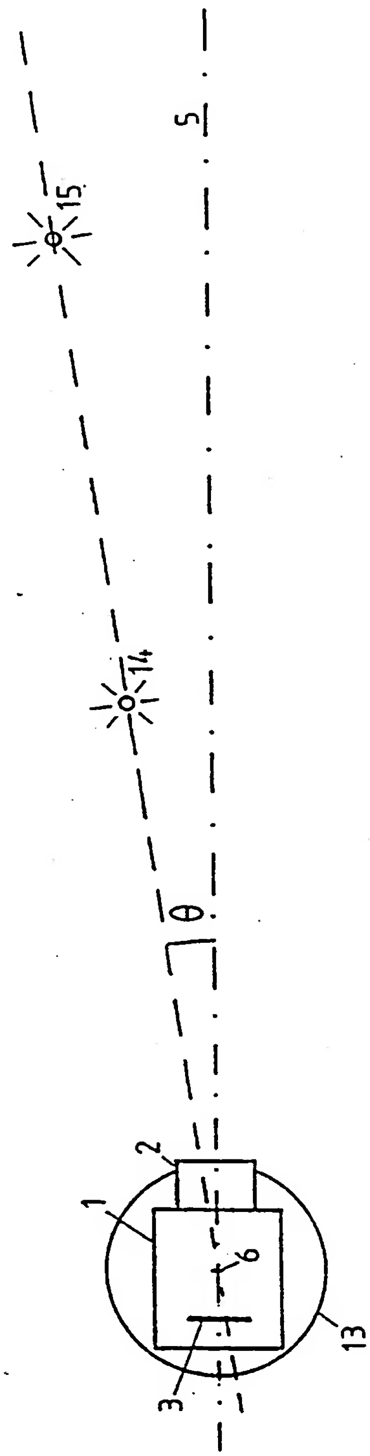


Fig. 3b

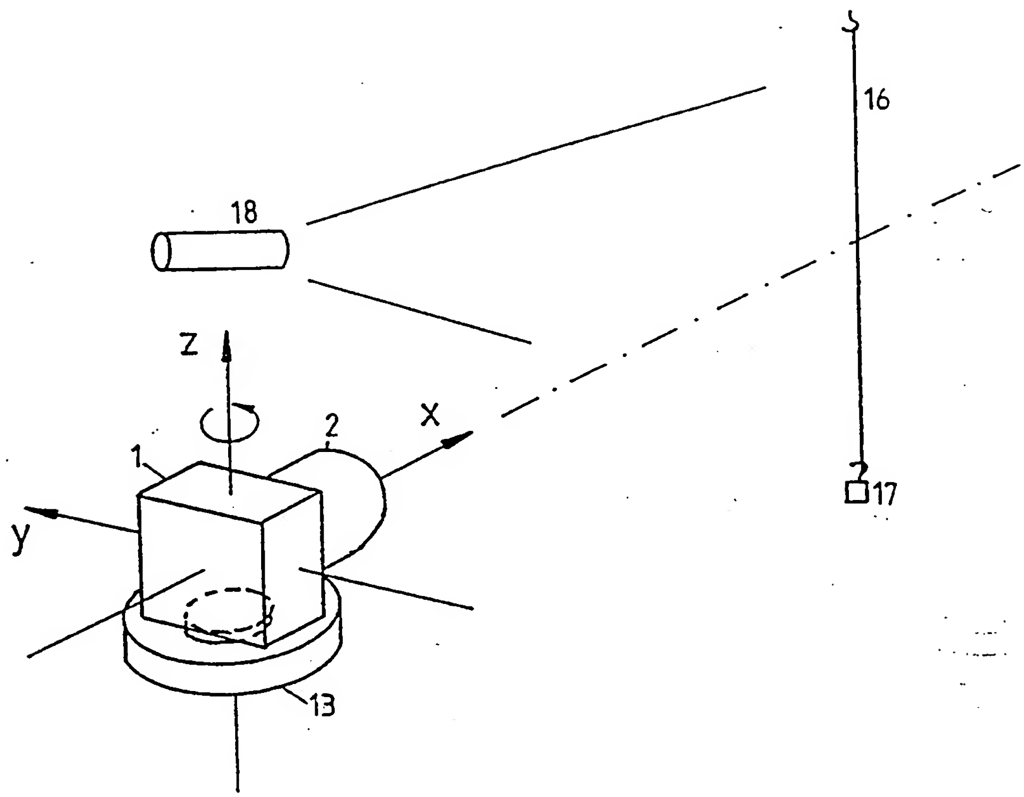


Fig. 4a

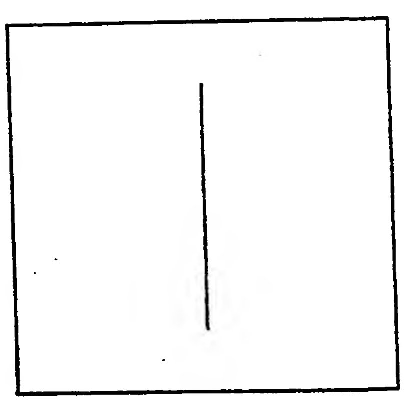


Fig. 4b

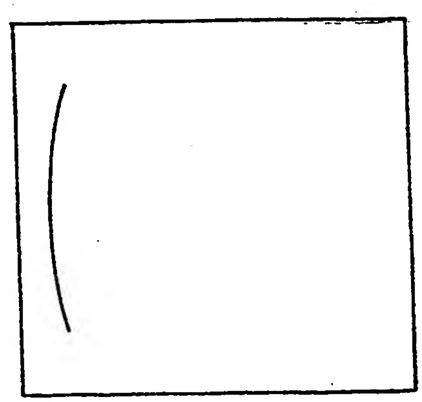


Fig. 4c

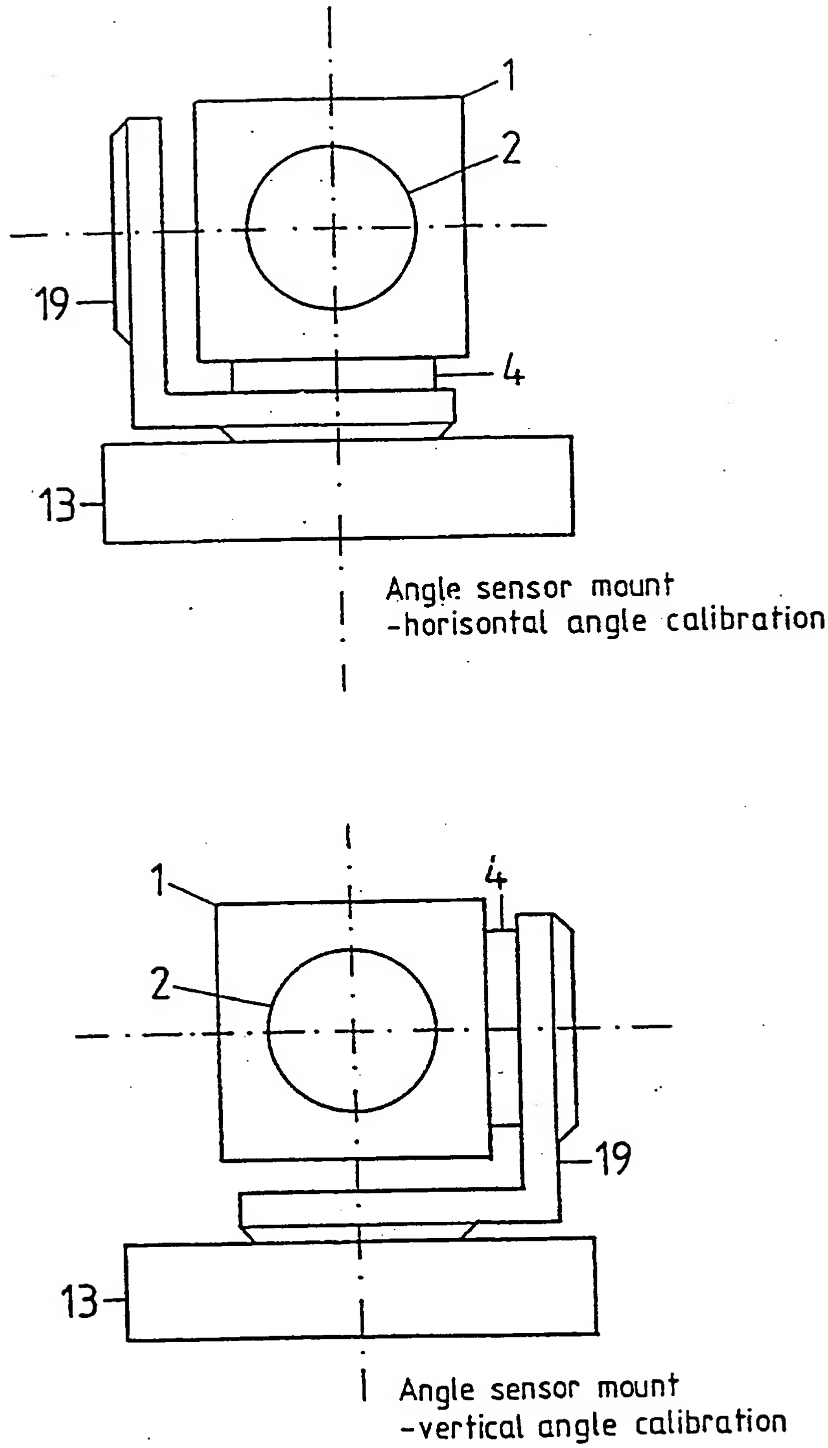

1
2
19
4
13
Angle sensor mount
-horisontal angle calibration
1
4
2
19
13
Angle sensor mount
-vertical angle calibration

Fig. 4d

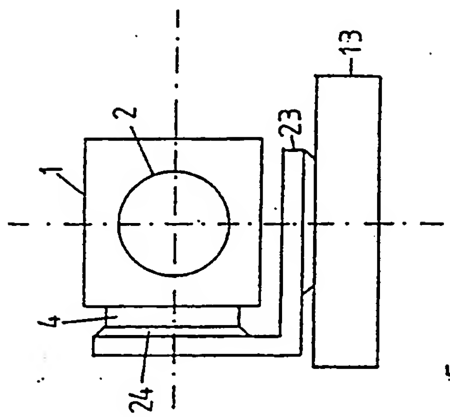


Fig. 5c

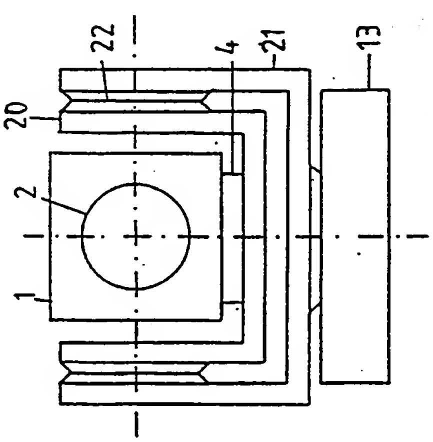


Fig. 5a

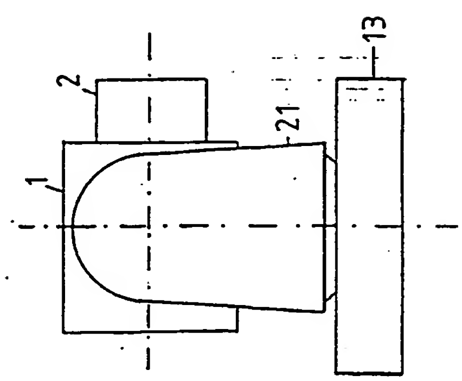


Fig. 5b

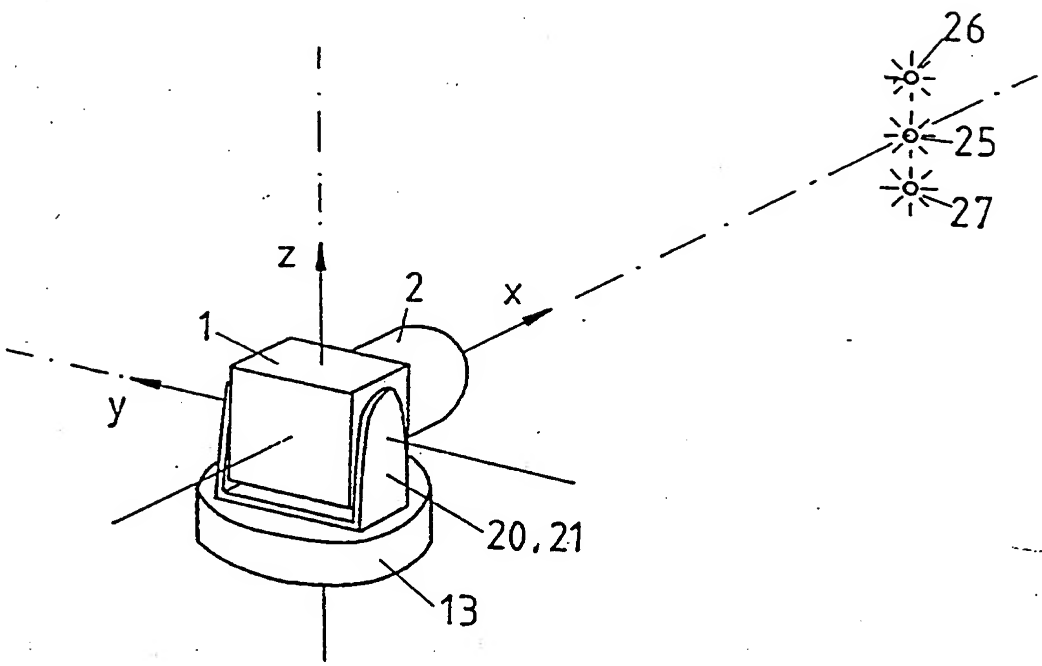


Fig. 6a

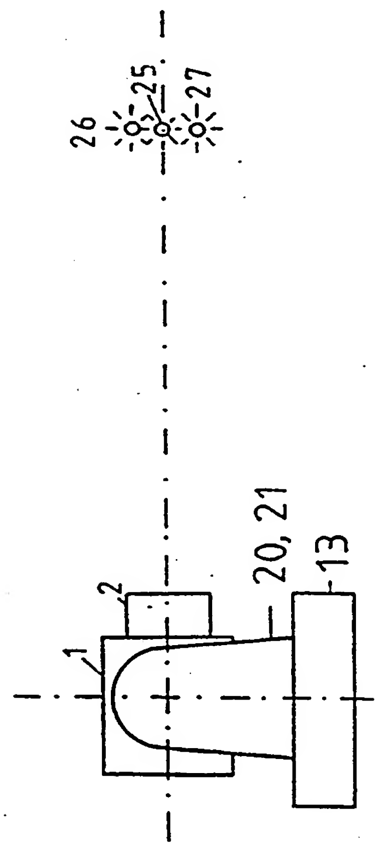


Fig. 6b

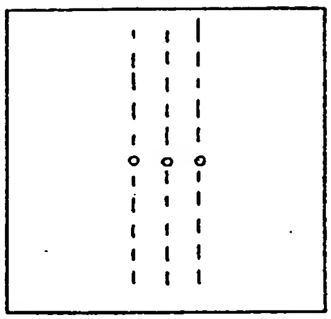


Fig. 6c

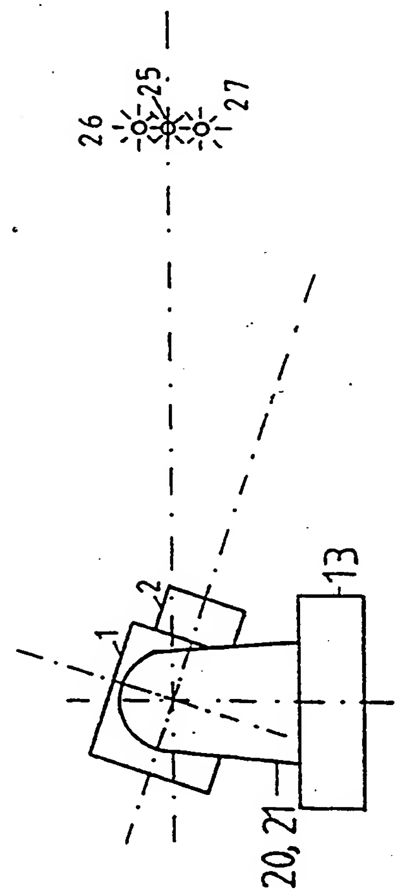


Fig. 6d

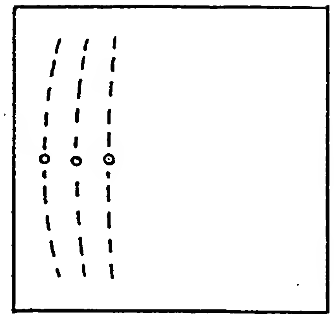


Fig. 6e

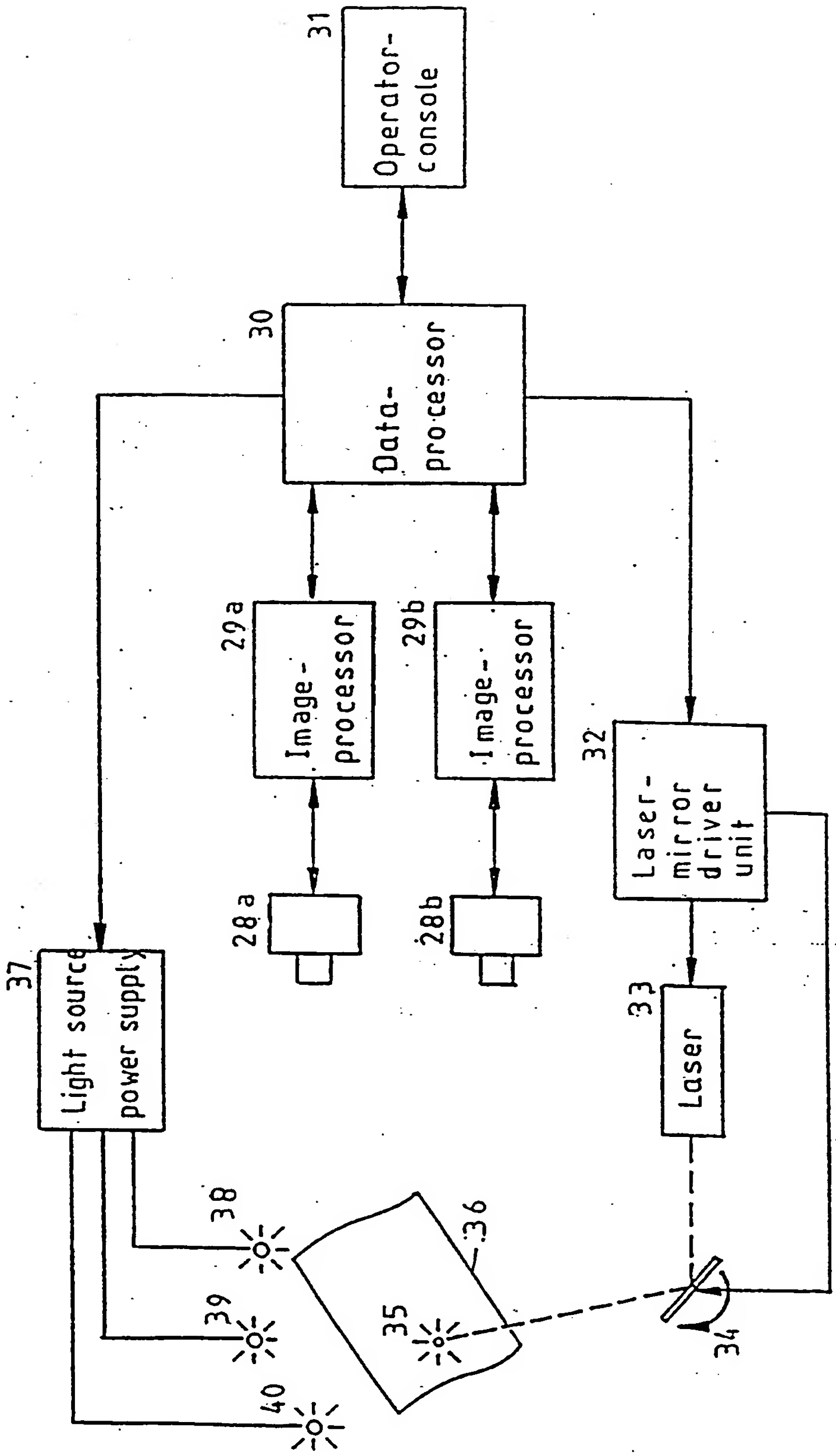

31
Operator-
console
30
Data-
processor
29a
Image-
processor
29b
Image-
processor
28a
28b
32
Laser-
mirror
driver
unit
33
Laser
37
Light source
power supply
38
39
40
35
36
34

Fig. 7

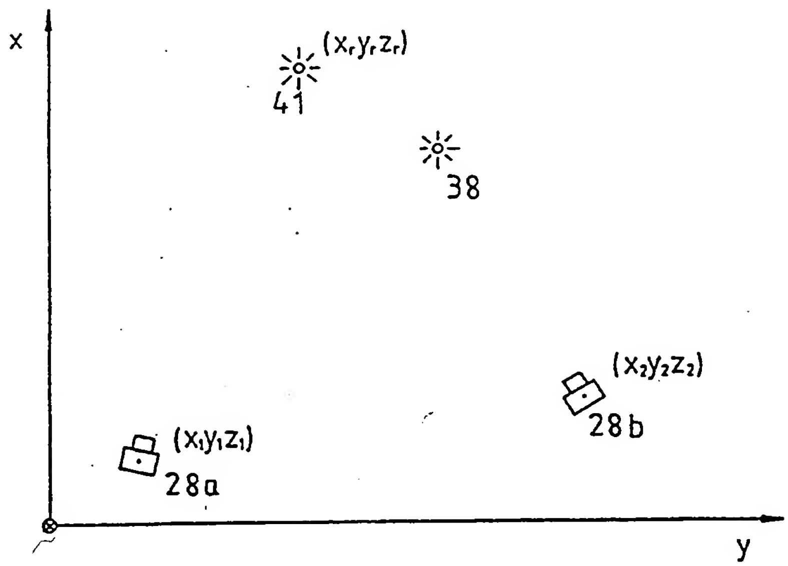

x
(xr yr zr)
41
38
(x2y2z2)
28b
(x1y1z1)
28a
y

Fig. 8a

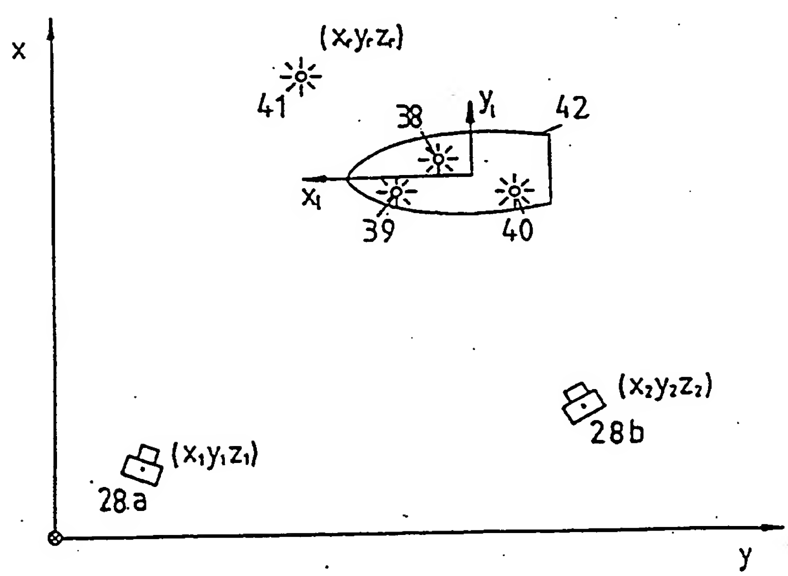

x
(xr yr zr)
41
38
y1
42
x1
39
40
(x2y2z2)
28b
(x1y1z1)
28a
y

Fig. 8b

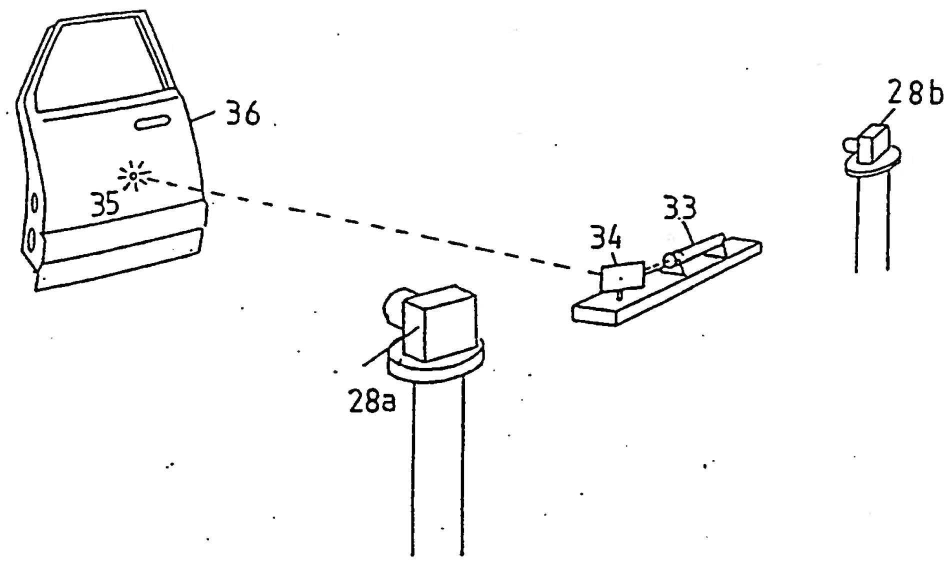


Fig. 8c

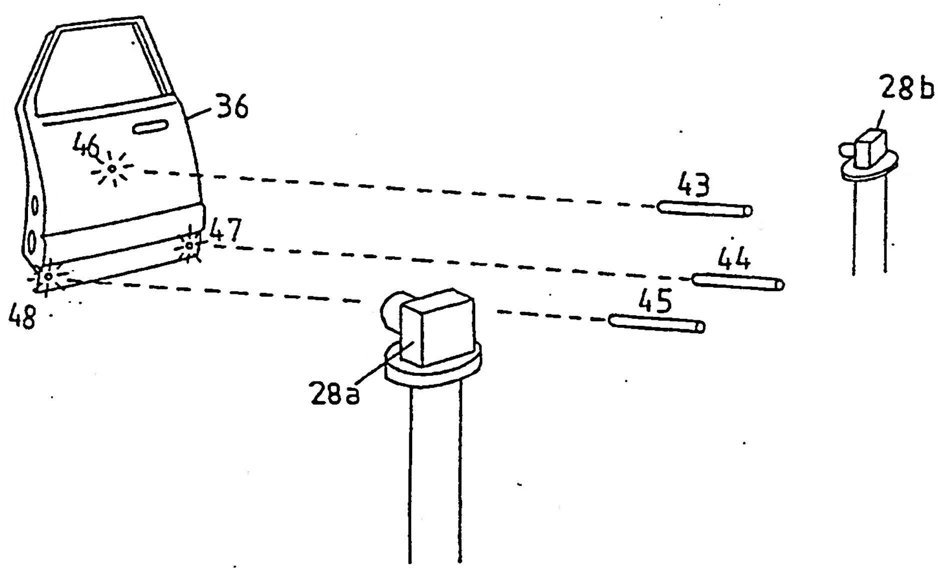


Fig. 8d

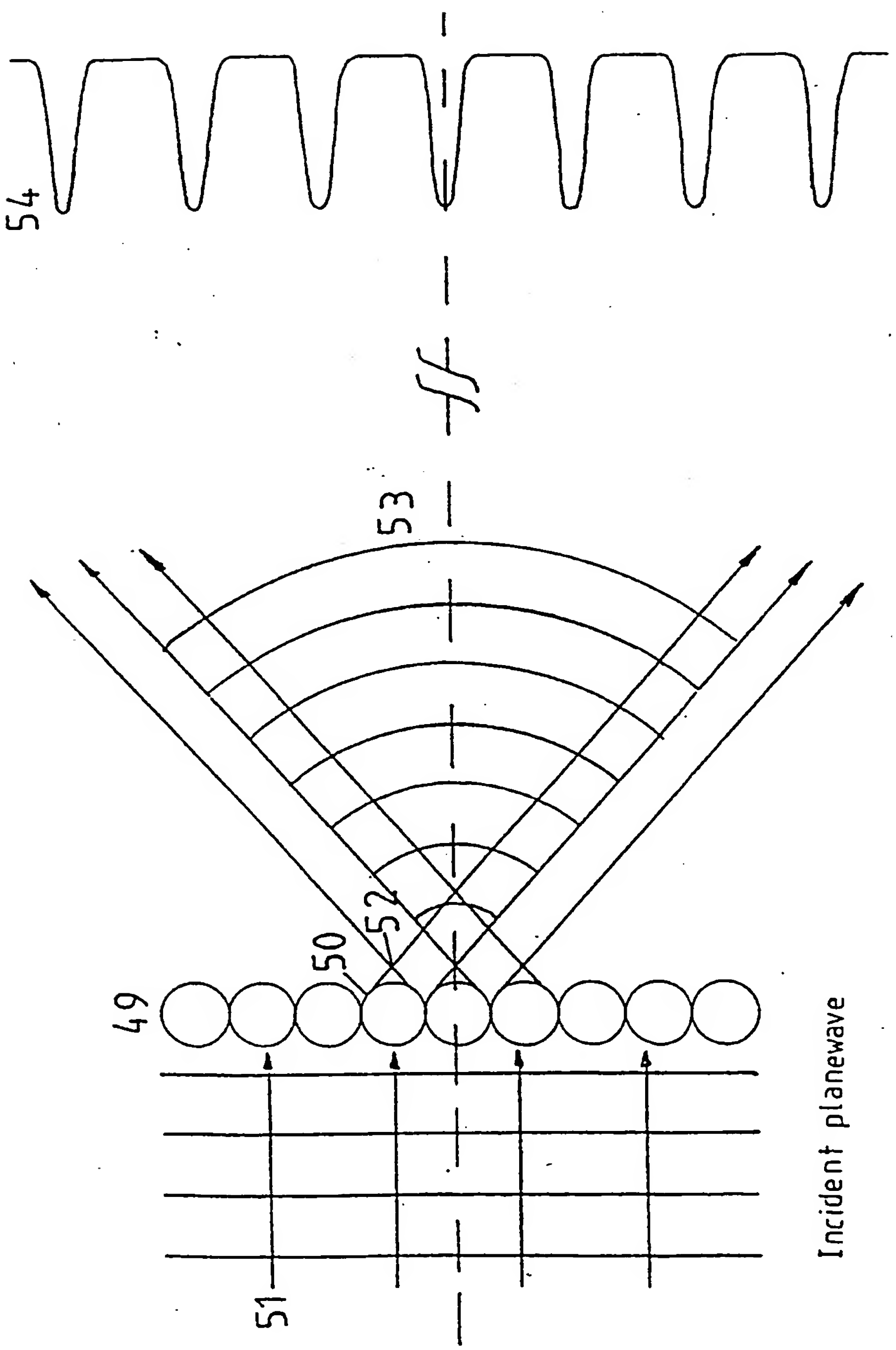

54
53
52
50
49
51
Incident planewave
Intensity distribution
of diffraction pattern

Fig. 9

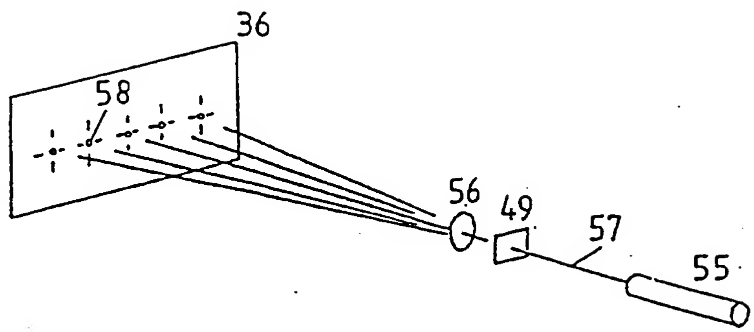


Fig. 10

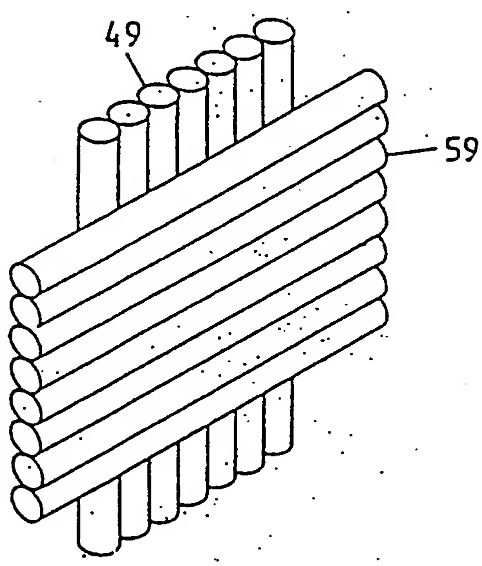
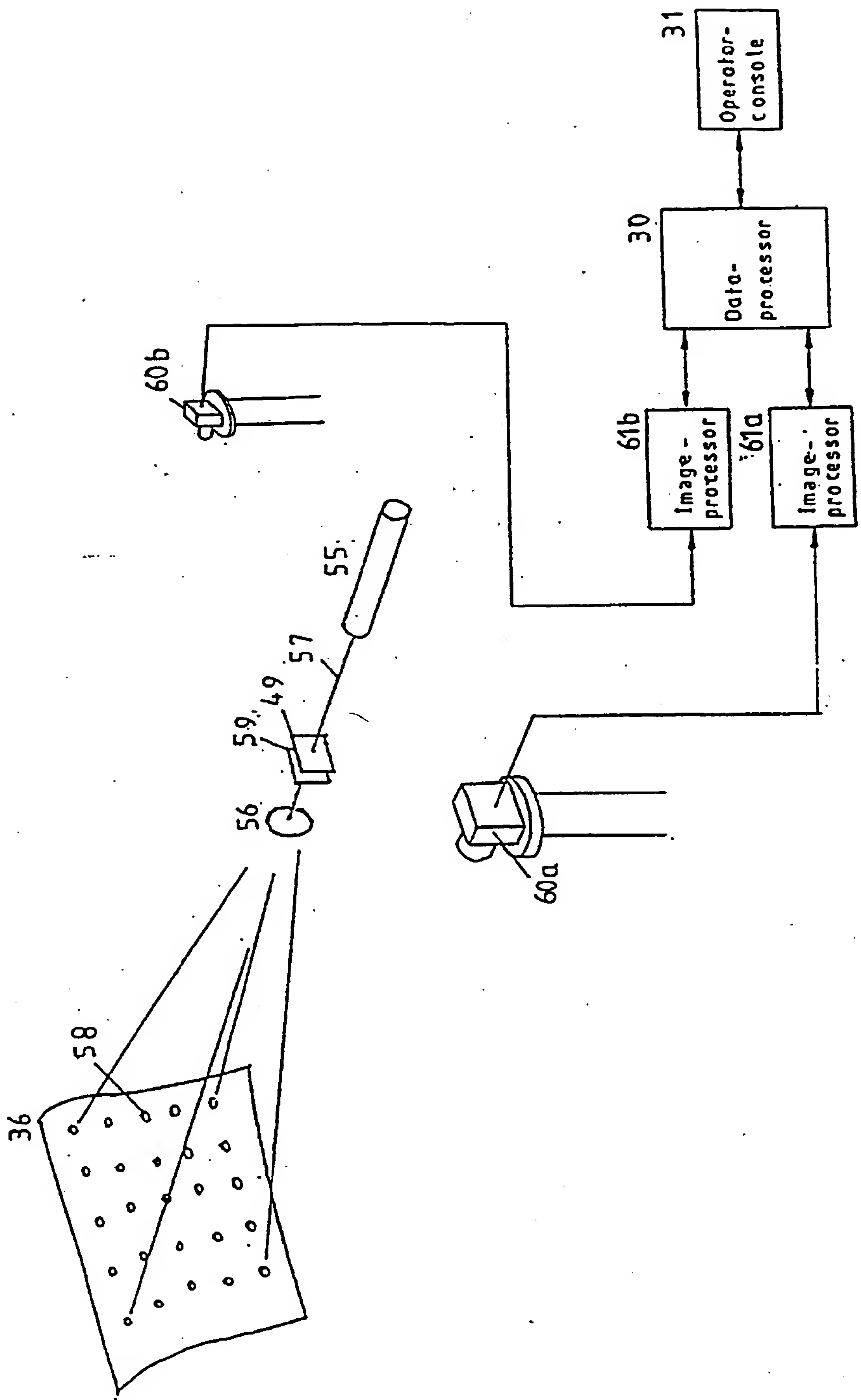


Fig. 11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Operator-
console
30
Data-
processor
61b
Image-
processor
61a
Image-
processor
60b
55
57
49
59
56
60a
58
36

Fig. 12

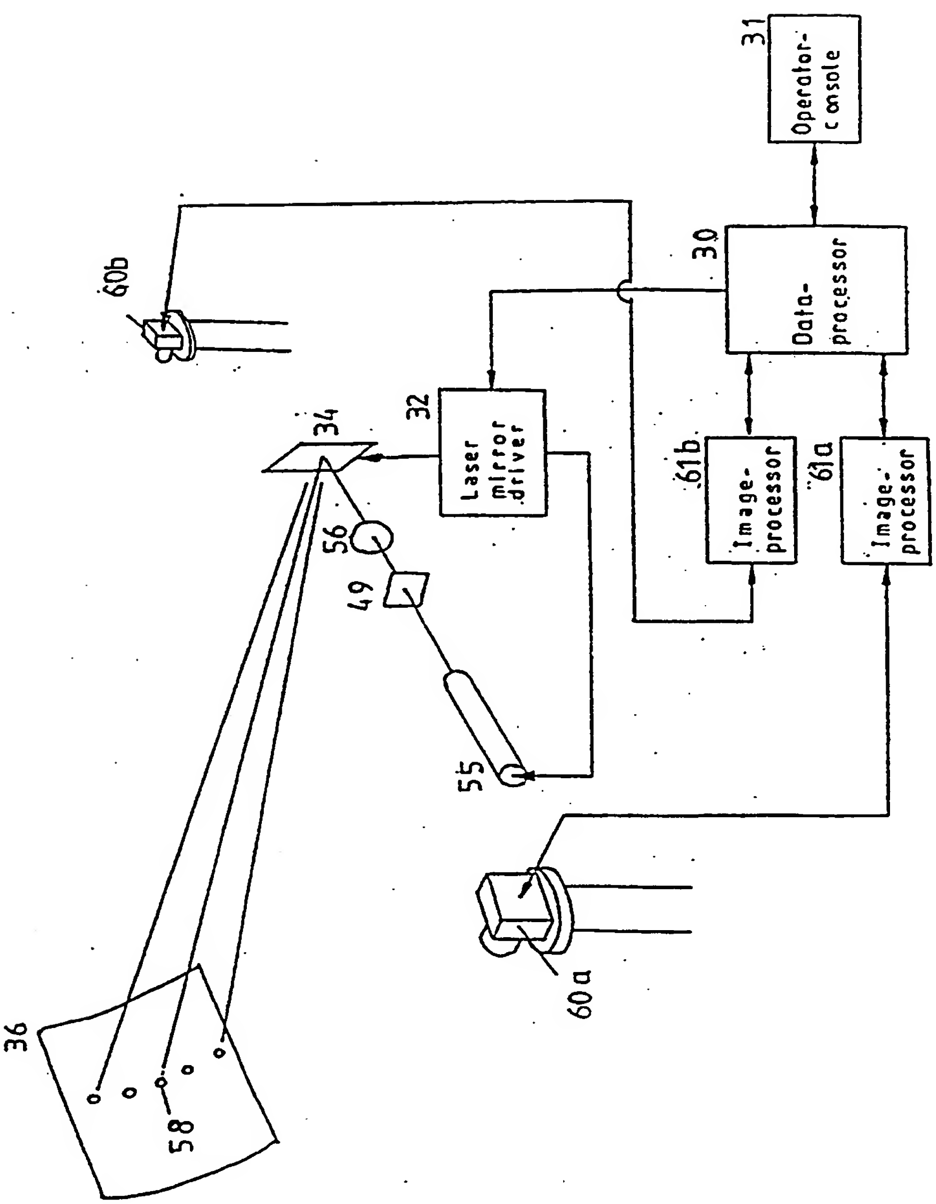
31
Operator-console
30
Data-processor
32
Laser mirror driver
34
61b
Image-processor
61a
Image-processor
56
49
55
60b
60a
36
58

Fig. 13